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NITRIFICATION AND DENITRIFICATION IN A MODEL WASTE STABILIZATION POND

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The University of Texas

CENTER FOR RESEARCH IN WATER RESOURCES

Environmental Health Engineering Research Laboratory

Department of Civil Engineering

NITRIFICATION AND DENITRIFICATION IN A MODEL WASTE STABILIZATION POND

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ABSTRACT

A laboratory model of a facultative waste stabilization pond was used to investigate nitrification and denitrification of milk wastes as a function of depth. The model was operated on a continuous flow basis using a dry milk product as feed. The organic and hydraulic loading were kept constant.

General pond characteristics were evaluated by measuring DO, ph, ORP and temperature profiles; COD and the different forms of nitrogen were monitored at frequent intervals during the test period to determine depth profiles of these parameters as well as COD removal efficiencies and nitrogen transformations.

A rapid removal of organics occurred in or near the bottom sediment layer with a correspondingly high degree of ammonification. Above the bottom layer the contents remained essentially unchanged except for minor variations due to algal density fluctuations. Detectable concentrations of nitrates were not found during the test period, but a substantial amount of nitrogen was lost from the liquid fraction. COD and nitrogen removals from the waste, as measured by the overflow, were 85% and 44% respectively.

CONCLUSIONS AND RECOMMENDATIONS

In evaluating the data obtained during the operation of the model stabilization pond, the following conclusions were reached:

1. A high hydraulic loading caused much of the algae to go out in the effluent, not allowing the algal population to build up to significant concentrations. This leads to the belief that the area/depth ratio was too small, since the algae exist near the pond surface from which the effluent was discharged.

2. Accumulation of organic debris on the bottom resulted in the formation of a highly enriched zone. In this zone the dissolved COD and organic nitrogen were removed rapidly from solution and a high degree of ammonification of dissolved organic nitrogen was observed.

3. Solid (particulate) COD and organic nitrogen can accumulate in high concentrations in the bottom deposits with only a small degree of stabilization of either COD or organic nitrogen in the solids.

4. A permanent aerobic zone is essential if nitrification is to take place. With anaerobic conditions prevalent during 50% of the time, nitrifying organisms were unable to function properly.

5. A facultative waste stabilization pond cannot accomplish denitrification of the nitrified effluent unless provisions are made for the treated waste to be recycled to an anaerobic pond where denitrification can proceed.

Recommendations: Detention time is of primary concern when utilizing a model which is scaled down in surface area only. The detention period should be long enough to permit an adequate population of algae to subsist in the pond at all times. During the course of this investigation it was determined that a detention period of 21 days resulted in somewhat limited algal growth. For operation of the model with increased algal densities, detention periods in excess of 30 days are recommended.

Further investigation with the model pond is suggested to determine the nitrogen removal characteristics of the model pond under different conditions. Of prime importance would be the reaction of the pond to variations in organic and nitrogen loading. The effect of phosphorus on nitrogen removal might also yield useful information. The operation of the pond might also be subjected to a domestic sewage loading of various degrees. Industrial wastes high in nitrogen present another possibility.

Since attention has been given to nutritional pollution resulting from secondary treatment plants, the possibility of removing excess nitrogen from sewage treatment plant effluents should be investigated in full. Of particular interest would be highly nitrified effluents low in organic matter. Denitrification could prove a feasible mechanism of nitrogen removal in this particular case.

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I. INTRODUCTION

Waste stabilization ponds can be used effectively to treat many types of wastewaters. This type of wastewater treatment facility is frequently inexpensive to construct and operate. The ability of these pond systems to reduce the biochemical oxygen demand (BOD) is well established. However, the fate of the nitrogen, its chemical form, within most pond systems is poorly understood.

Facultative waste stabilization ponds, as compared to other pond systems, are most widely used. These ponds maintain an aerobic and anaerobic environment, respectively, near the surface and bottom. Biologically these are complex systems, but generally effective in removing BOD.

In systems where the buffer between the aerobic and anaerobic zones may change due to wind action, etc., it would be desirable to know if it is possible to estimate the degree of nitrification and denitrification that occurs at various depths under certain operational conditions. The biological conversion of reduced forms of nitrogen to nitrates is termed nitrification, and the reduction of nitrates to molecular nitrogen is termed denitrification.

Present methods of waste treatment emphasize the removal of organic compounds. If treatment methods are not improved and extended, pollutional problems related to the discharge of nutrients will overshadow the effects of oxygen consuming waste effluents (31). Thus the removal of nutrients such as nitrogen and phosphorus becomes of prime concern.

Nitrogen, along with phosphorus, is believed by many to be the key to nutritional pollution since it is usually in limiting amounts for algal

growth to occur in oligotrophic waters. Nitrogen appears to be present in far less abundant supply, relative to need, than phosphorus for algal growth (16), and for this reason its removal would seem to be of greater importance.

In recent years, the eutrophication of surface waters (streams, lakes and estuaries) has become an ever-increasing problem. Eutrophication of a body of water, in nature, is usually a very slow process whereby the nutrient content of the water increases and hence its productivity. Productivity is manifest in gross algal growths which produce taste and odor problems, as well as making the water unsightly and undesirable for recreational use.

Eutrophication has been unintentionally speeded up by man. With the increased use of inorganic fertilizers, the nutrient content of agricultural runoff has reached significant proportions in most areas of the country. Another source of nutrients is found in the effluent from primary and secondary waste treatment plants.

The ultimate source of nitrogen is the atmosphere and all nitrogen compounds are derived indirectly through fixation of molecular nitrogen in the atmosphere. Changes in the concentration of molecular nitrogen involve nitrogen fixation, bio-assimilation, and denitrification. Fixed or bio-assimilated nitrogen is incorporated into the protein structure of organisms and upon death the nitrogen is released for reuse through the well established nitrogen cycle (24).

Loss of nitrogen from wastewaters in a waste stabilization pond occurs through diffusion of volatile nitrogen compounds from the surface, denitrification, formation of semi-bound sediments, and release in the effluents. The fraction of nitrogen lost through the effluent is of importance to sanitary engineers since it is directly involved in the nutritional pollution of the receiving waters.

One of the cheaper methods of removing nitrogen from wastes appears to be biological oxidation of organic material. The microorganisms utilized in these processes require nitrogen for cell growth. When a high degree of treatment is given to the wastewater, large concentrations of nitrates (NO_3^-) appear in the effluent. The nitrates are readily available to aquatic plants and algae (4), hence removal of nitrates is becoming increasingly more desirable.

Objective

The purpose of this study was to determine if a laboratory model, scaled down in area only, could be used to study the nitrogen cycle. A model of a facultative pond would provide both aerobic and anaerobic conditions for nitrogen transformations to proceed.

Specifically, it was planned to measure the influence of depth (algal-bacterial densities) on nitrification and denitrification, especially when the algal density (reoxygenation capability) was limited.

Scope

This study was limited to a laboratory model of a facultative pond system embracing a fixed organic and volumetric loading rate. Environmental conditions such as sunlight, depth, and wind were simulated.

Nitrification and denitrification, with respect to COD removal at various depths was studied by measuring total nitrogen, ammonia-nitrogen, nitrite and nitrate-nitrogen and COD. Other tests were conducted to support the primary objectives.

II. LITERATURE REVIEW

Past research on waste stabilization ponds has yielded valuable information for the design of these units in stabilization of organic wastes. However, little is known about the nitrogen transformations and removal characteristics of waste stabilization ponds. The work of others has been, to date, limited to the observation of total nitrogen removal occurring in pond effluents. As yet, no attempt has been made to investigate the mechanism and degree of nitrogen utilization in the pond system itself. The following paragraphs contain information on the better known mechanisms of nitrogen metabolism of micro-organisms in biological systems, a review of nitrogen transformations in different pond systems, and a review of previous work on nitrogen removal by means of different types of pond systems.

2.1 The Nitrogen Cycle

The relationships that exist between the various forms of nitrogen compounds and the changes that can occur in nature are best illustrated by a diagram known as the nitrogen cycle, shown in Fig. 1 (35). In Fig. 1 the oxidation of nitrogen is shown as solid lines; the reduction of nitrogen is shown as dashed lines, and reactions involving no valence change are shown as dotted lines.

Many organisms can derive their energy either directly or indirectly from nitrogenous compounds. First, there is the fermentation and oxidation

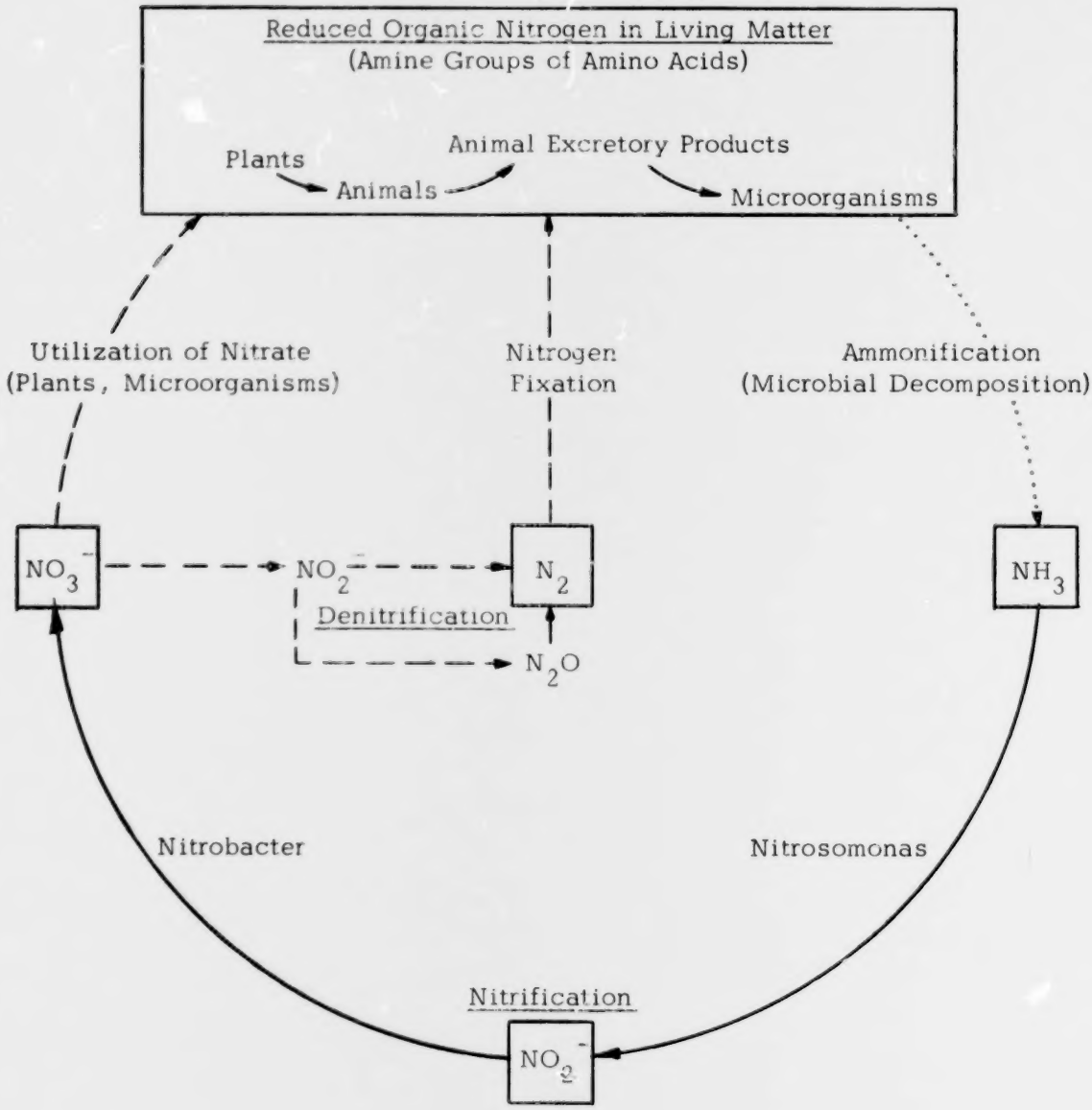


FIG. 1. THE NITROGEN CYCLE IN NATURE

of amino-acids (ammonification) by heterotrophs and second are the autotrophic nitrifying bacteria. In nature the ammonia produced may suffer one of three fates: (a) oxidation by the nitrifying bacteria to nitrate (nitrification), (b) after oxidation to nitrate, conversion to molecular nitrogen and nitrous oxide (denitrification), or (c) incorporation into organic molecules (13).

Nitrification: Those microorganisms which carry out the oxidation of ammonia to nitrite and nitrate (nitrification) are commonly known as chemosynthetic bacteria. These organisms use carbon dioxide as their only source of carbon and obtain energy for growth through the oxidation of ammonia to nitrite and nitrite to nitrate. Two different groups of organisms carry out these oxidations: Nitrosomonas, oxidizes ammonia to nitrite and Nitrobacter, oxidizes nitrite to nitrate (35).

The oxidation of ammonia to nitrite as carried out by Nitrosomonas can be written as:

$$NH_3 + 3/2\ O_2 \longrightarrow NO_2^- + H_2O + 2H^+$$

The oxidation of nitrite to nitrate by Nitrobacter can be represented by the following equation:

$$NO_2^- + 1/2\ O_2 \longrightarrow NO_3^-$$

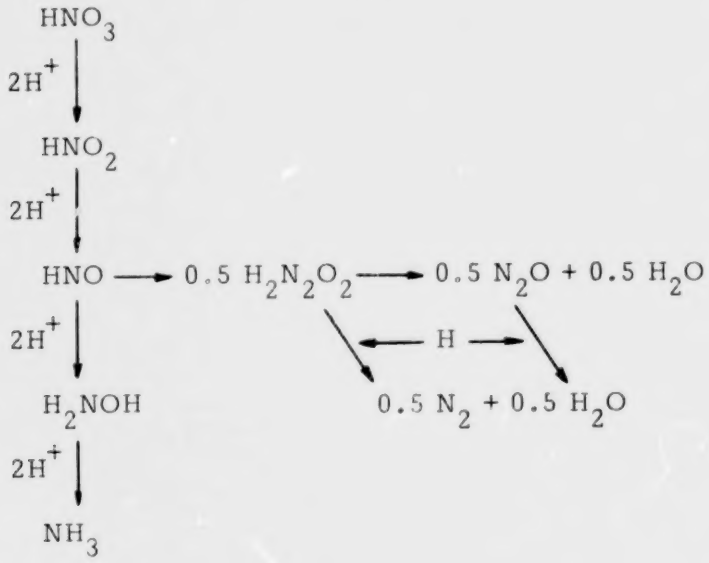
Both reactions produce energy, although the latter has a lower yield and hence requires three times the amount of substrate to produce an equal

amount of energy. The free energy change being -66,500 and -17,500 calories respectively (5). Nitrification does not readily occur until most of the carbonaceous material has been removed and considerable auto-oxidation of cellular material has released additional nitrogen to solution (8). Many of these organisms prefer an alkaline environment, but a high concentration of NH_4^+ will inhibit the oxidation of NO_2^- and the higher the pH of the medium the greater the inhibition, both of growth and nitrite oxidation (13).

Denitrification: In contrast to the limited number of organisms capable of oxidizing NH_3 and NO_2^-, numerous species are able to reverse the reaction, that is, reduce NO_3^- and NO_2^- to NH_3, N_2O and molecular nitrogen. Although NH_3 may be retained in the organism or in the medium due to its high solubility, gaseous products like N_2 and N_2O may pass readily into the atmosphere thus reducing the overall nitrogen content of the organism's immediate environment (13). Examples of organisms known to reduce NO_3^- include Ps. fluorescens, Ps. denitrificans, Ps. stutzeri Micrococcus denitrificans and Thiobacillus denitrificans.

The actual reduction of nitrates occurs in at least three ways depending upon the utilization of the nitrate (6). In the first case, the nitrate is used directly for assimilatory purposes after it has been reduced to the level of ammonia present in the amino groups of cell protein. In a second case, the nitrate competes with other hydrogen acceptors for hydrogen derived from organic substrates. This type of reaction is not

essential to cell growth. In the third case, organisms utilize nitrate as a terminal electron acceptor rather than using molecular oxygen. This type of reaction can result in the complete reduction of NO_3^- to NH_3. Although the actual sequence of NO_3^- reduction is unknown, Kluyver originally postulated the following scheme (6):



It has been shown (6) that under relatively high oxygen tension, nitrate reduction is completely inhibited. Whereas, under reduced oxygen tension NO_3^- goes to NH_3 and in the absence of oxygen, N_2O and N_2 are formed.

Denitrification proceeds best under anaerobic conditions and with an available carbon source to provide energy for the denitrifying bacteria, as illustrated below (8):

$$NH_3 \longrightarrow NO_3 + \underset{\text{C-source}}{\overset{\text{No D. O.}}{\longrightarrow}} N_2,\ N_2O$$

NITRIFYING ORGANISMS — FACULTATIVE ANAEROBIC BACTERIA

This release of nitrogen to the atmosphere is of great importance where nutrient removal is desirable.

The only way for nitrogen to re-enter the system would be through nitrogen fixation, which can be accomplished by a considerable number of bacteria and some blue-green algae (28). Without nitrogen-fixing organisms all life would eventually cease on earth, as all of the nitrogen would be converted to the relatively inert molecular form.

2.2 Waste Stabilization Ponds

K. Wuhrmann (38) has done considerable work with nitrification and denitrification in activated sludge as a means of removing nitrogen from treated effluents. Wuhrmann has suggested that stabilization ponds could operate in a similar fashion to provide nitrogen removal.

Basically, the nitrogen would be removed by three different mechanisms: (a) as molecular nitrogen produced through bacterial denitrification, (b) as ammonia (NH_3) adsorbed on the soil and (c) as cellular nitrogen in the algae themselves. By converting a large part of the nitrogen in wastes into molecular nitrogen, it is essentially removed from the biosystem since most organisms cannot utilize it in this form (5). The solubility of molecular nitrogen is 2.33 $cm^3/100$

cm^3 of water at 0^oC and that of NH_3 is 89.9 gm/100 cm^3 of water. Most organic nitrogen will be converted to ammonia in and near the sediment where anaerobic conditions predominate. Ammonia nitrogen from the sediment diffuses to the soil where it can be easily adsorbed by clays. Harvesting the algae alone would result in the removal of up to 50% of the nitrogen in the influent (38).

Role of Bacteria: The degradation of organic materials in a stabilization pond is brought about primarily by bacteria. The biological reactions carried out by bacteria in stabilization ponds include: (a) oxidation of carbonaceous organics by aerobic bacteria, (b) reduction of carbonaceous organics by anaerobic bacteria living in sediments and bottom liquids, (c) nitrification and denitrification of nitrogenous compounds by aerobic and anaerobic bacteria respectively (17).

In aerobic respiration bacteria utilize most of the organic carbon compounds as a source of energy, the carbon being respired as carbon dioxide. The remainder of the carbon is incorporated into new cell material along with such nutrients as nitrogen and phosphorus.

The fate of organic nitrogenous compounds is hydrolysis to ammonia through bacterial processes. Proteins undergo degradation to amino acids by proteolytic enzymes. The amino acids, in turn, are deaminated to ammonia, carbon dioxide and water (37). These processes are complicated by a host of simultaneous reactions involving the assimilation of organic nitrogen and ammonia and the nitrification and

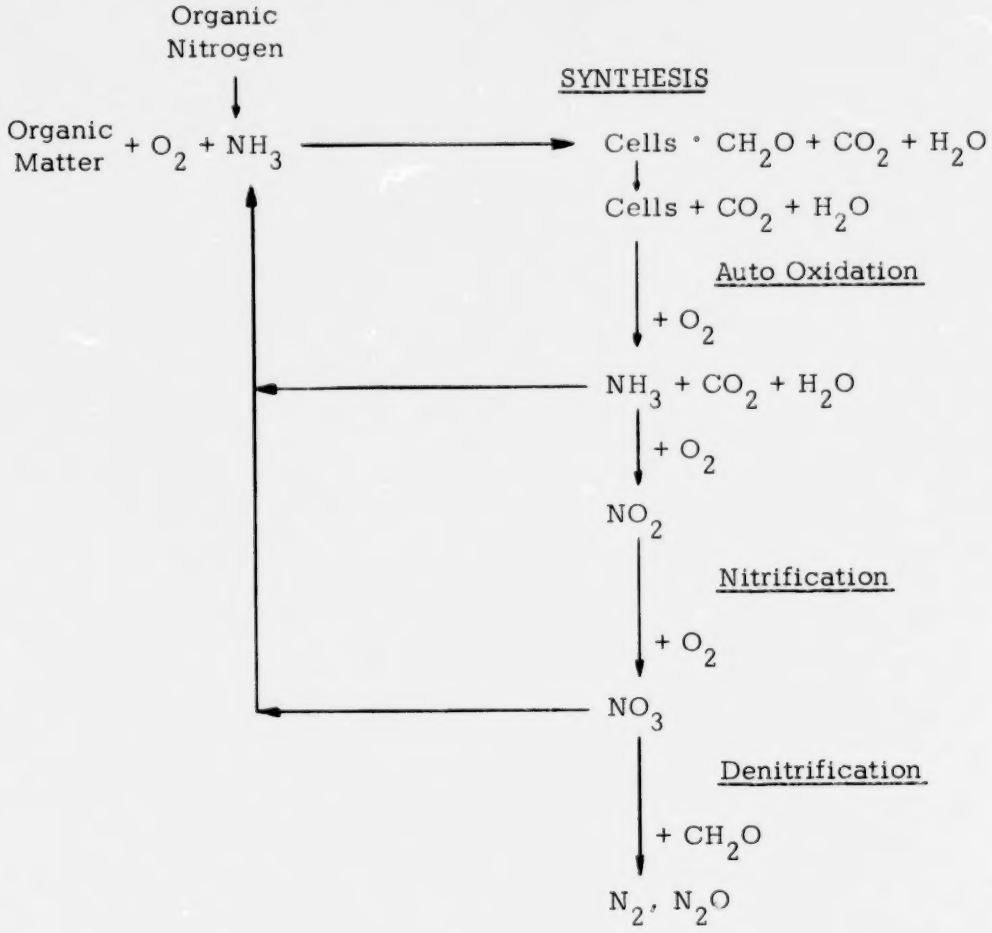


FIG. 2. THE NITROGEN CYCLE BIOLOGICAL OXIDATION PROCESS

denitrification processes. A summary of the nitrogen cycle in biological oxidation processes is given in Fig. 2 (9).

Role of Algae: In a waste stabilization pond algae are introduced to help provide an aerobic environment. The algae utilize the carbon dioxide produced by the bacterial oxidation of organic compounds and, in turn, supply the oxygen necessary for bacterial respiration.

Growth of algae is influenced by temperature and the level of available nutrients (10). Algae utilize, for growth, mineral nutrients as well as carbon dioxide dissolved from the air or released from organic decomposition. The optimum temperature for the more common species of fresh water algae (Chlamydomonas, Chlorella, Euglena and others) in ponds is between 15-30^{o}C (11). An optimum pH range for algae in general is between 7-8.

Sewage contains an abundant supply of algal nutrients; the most important of which are tabulated in Table 1 (11).

Algae, with few exceptions, can utilize either ammonium or nitrate salts when present at the appropriate concentration (22). Nitrate must undergo reduction before it can be incorporated into amino-acids and other nitrogenous cellular components (12). Ammonium salts are generally more readily assimulated than nitrate, but since ammonium enters the cells more readily as undissociated NH_4OH, the medium surrounding the cell becomes more acid and may eventually reach a pH sufficiently low to inhibit growth (12). Only if the system is well

TABLE 1. AVERAGE COMPOSITION OF SEWAGE

Nutrient	Concentration (mg/l)
Total Nitrogen	20- 50
NH_3-N	7- 40
NO_3-N	0- 4
NO_2-N	0- 0.3
Organic-N	3- 42
Calcium	66-176
Soluble Phosphorus	1- 13
Potassium	13- 44

buffered will growth be as good with NH_4^+ as with NO_3^-. Some autotrophic algae are also known to be capable of utilizing various organic nitrogenous substances as their only source of nitrogen (12).

Nitrogen Removal: The growth of algae, the primary producers in an ecosystem, is regulated in part by inorganic carbon, nitrogen and phosphorus. Therefore, excessive growths, a most probable result of abnormally high concentrations of these nutrients, might be used to remove nutrients from effluents of waste stabilization ponds (15). Numerous studies indicate a wide range of conditions and removal efficiencies of both organic pollutants and algal nutrients (1, 3, 10, 11, 20, 21, 25, 30, 31).

The concentration of nitrates in the effluent of stabilization ponds varies greatly, but seems to depend mostly on the organic loading on the ponds. Parker (30) reports a gradual increase of nitrate (from 0 to 0.77 mg/l), in a series of 8 ponds, as the organic loading decreased to each subsequent pond in the series. Hermann (18) observed the reduction of nitrates in aquaria studies upon addition of an abundant carbon source. This latter observation indicates that the mechanism for nitrate reduction was most probably denitrification. It is also known that carbon deficient algae will increase their rate of metabolism and thus the utilization of nutrients, upon the addition of an ample source of carbon (12). Meron et al (25) have reported a case where only 30% reduction in total-nitrogen occured due to what appeared to be a lack of carbonaceous material.

Removal of ammonia nitrogen has been reported (11) down to less than 2 mg/l (70-90% reduction). Fitzgerald (10) has reported the almost complete utilization of ammonia, from sewage effluent by Chlorella in the lab, before nitrate was utilized in significant amounts. The nitrite level increased to 1.5 mg/l during the period of ammonia utilization and was sharply reduced in the subsequent period of nitrate utilization. The increase in nitrite was obviously bacterial since nitrification is not known in algae, but the utilization of nitrate and NH_3 was probably due to the combined effects of algae and bacteria.

The reduction of total nitrogen is due mostly to bacterial action since most of the inorganic nitrogen taken up by the algae is converted to organic nitrogen and released to the system upon lysis. Organic nitrogen has been reported (11) removed from solution to a level of 60% most of which was the result of bacterial action since algae utilize very limited amounts of organic nitrogen. The range of total nitrogen removal most often reported (1, 3, 10) is between 30-90%.

Assenzo and Reid (1) have developed response surfaces for BOD/N/P ratios for optimum nutrient removal in central Oklahoma ponds. For optimum removal of nitrogen the ratios ranged from 78/13/1 to 16/8/1. The loadings for optimum removal were approximately 52 lbs of BOD_5 per acre per day, 12.0 lbs of nitrogen per acre per day and 1.6 lbs of phosphorus per acre per day. Of the seven ponds studied only two had detention periods between 15-30 days. The other ponds had detention periods in excess of 70 days.

Oswald (29) and Loehr and Stephenson (23) have analyzed the gases evolved from the bottom waters and sediment of facultative ponds, and have found the gases to contain from 60 to 67% nitrogen respectively. Oswald found the rest of the gas to consist of mostly CH_4 and in Loehr's case it was mostly O_2. The presence of oxygen in Loehr's case is indicative of aerobic conditions near the bottom where methane fermentation should be operative as in Oswald's case.

2.3 Eutrophication

Conventional treatment does not remove nitrogen and phosphorus in sufficient quantity to prevent algal growths in the receiving bodies of water. Since nitrogen and phosphorus are not abundant in surface waters, they seem to be, most often, the limiting factor in algal growth (2). Sewage nutrients, after dilution in surface waters, are effective for growing algae, although somewhat restrained.

Sawyer's (33) work on several southeastern Wisconsin lakes seems to indicate that nuisance conditions will occur when the concentration of inorganic phosphorus exceeds 0.015 mg/l the concentration of inorganic nitrogen exceeds 0.3 mg/l at the time of the spring overturn. These concentrations apply only to the lakes under study and no direct correlation can be made for conditions in the rest of the country. However, problems may occur at concentrations of phosphorus and nitrogen of only a few tenths of micrograms per liter (36).

III. MATERIALS AND METHODS

In order to study the various relationships of nitrogen with respect to depth a model was designed to simulate, as close as possible, a facultative waste stabilization pond. The model, scaled down in all respects except depth, was to provide an environment for both algal and bacterial systems to operate. The model was kept as simple as possible in order to facilitate construction and operation.

3.1 Model Pond Design

The design of the model was governed by the fact that it was desired to simulate a facultative waste stabilization pond inside the laboratory. To accomplish this, two 55 gallon drums were welded together on ends. This provided a model pond having a depth of six feet and a diameter of two feet. The complete model pond is shown in Fig. 3.

Six sampling ports were provided at approximately one foot intervals down the side of the model. A gate valve on the bottom port facilitated feeding. The other sampling ports consisted of rubber stoppers, with a short piece of glass tubing through the middle, inserted in each of the five 5/8 inch diameter holes. Each glass tube had a piece of tygon tubing attached to it and a pinch clamp serving as a valve. The inside of the model was coated with a fiber glass resin to retard rusting.

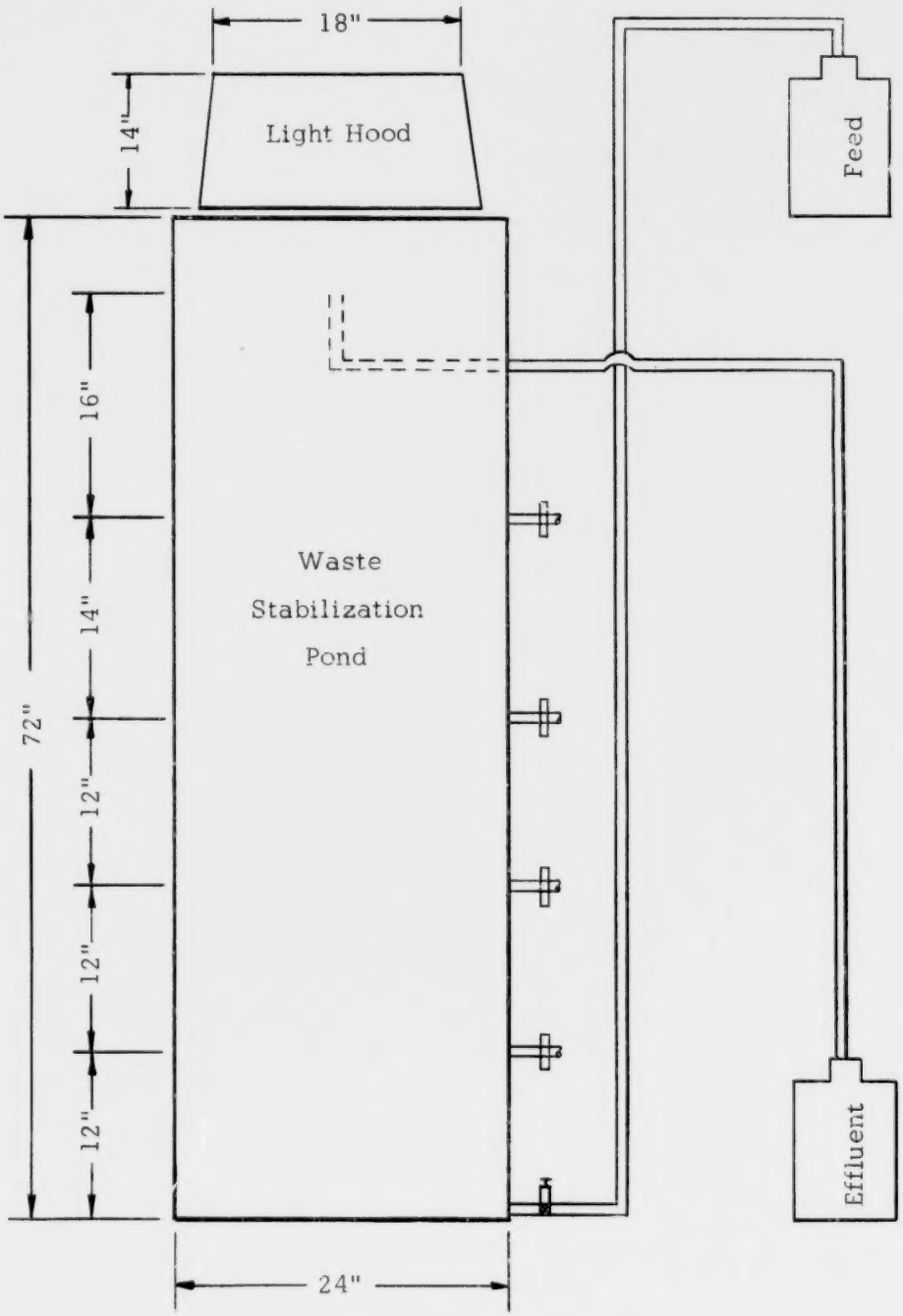


FIG. 3. SCHEMATIC FOR THE MODEL WASTE STABILIZATION POND

Artificial light was used to illuminate the model pond. The lighting arrangement consisted of a hood of galvanized metal (18 inch diameter at top, 20 inch diameter at bottom, and 14 inches deep), suspended from the ceiling, with a fixture for circular fluorescent lights and one incandescent light bulb attached to the top. The lights consisted of one fluorescent bulb each of 40, 32 and 22 watts and one 60 watt incandescent bulb. This arrangement supplied 600 foot-candles at the center of the pond surface. The light intensity decreased down to 400 foot-candles at the peripheral edge of the model. A ratio of approximately 2:1 was attempted between fluorescent and incandescent light in an attempt to simulate sunlight (7). The lights were hooked up to a timer which turned them on at 8:00 a.m. and off at 8:00 p.m.

To prevent the formation of a scum layer and at the same time impart a slight rotational movement to the water, a surface mixing device was installed in the top of the model pond. The surface mixing device consisted of a small electric motor (4 rpm) with a 20 inch length of welding rod attached to the shaft. The device was suspended above the surface of the pond in such a manner as to allow the welding rod to be submerged about 1/2 inch. The ripple caused by the welding rod was sufficient to keep the surface free of scum but not great enough to interfere with the thermocline.

3.2 Feed

A loading of 50 lbs BOD_5/acre/day was chosen since it was close to the optimum for nitrogen removal found by Assenzo and Reid (1). It was believed that at this level the loading would be low enough to permit nitrification in the aerobic zone of the model, and also supply sufficient carbonaceous material to the anaerobic denitrifying zone.

A powdered milk, Starlac, was chosen as the waste. From a BOD analysis of a solution of Starlac and the hydraulic characteristics of the model it was determined that a 5 gallon solution containing 121 mg/l of Starlac and 10.5 mg/l of K_2HPO_4 (dibasic potassium phosphate) would provide a loading of 50 lbs BOD_5/acre/day. The dibasic potassium phosphate was added to supplement the amount of potassium and phosphorus in the milk and also to buffer the system against the acidic character of the milk waste. The approximate composition of Starlac, as given by the manufacturer's label, is shown in Table 2.

A detention period of 21 days was chosen mainly to provide ample time for the algae to proliferate. It was noticed that the algae grew in a small zone near the top and if the hydraulic load was made too great most of the algae would be washed out in one day's effluent. A long detention period would also permit the stabilization of the organic material to a level where nitrification processes would be enhanced.

The model pond was fed on a daily basis. Five gallons of feed solution were fed from a carboy by means of a siphon through a

TABLE 2. COMPOSITION OF STARLAC

Food Factor	Dry Weight (%)
Protein	36
Lactose	51
Milk Fat	0.8
Minerals	8.2
Calcium	1.3
Phosphorus	1.0
Iron	0.0000
Sodium	0.525
Potassium	1.725
Moisture	4.0

small capillary tube. The feeding operation was initiated daily at 8:00 a.m. Approximately 12 hours were required for five gallons of feed solution to enter the model.

The effluent was collected in a graduated container which made it possible to determine evaporation losses. The evaporation losses were replaced daily with tap water.

3.3 Sampling and Test Procedure

Samples were collected every other day just prior to the time when the lights over the pond were turned off. Two hundred milliliters of sample were taken from each depth (0, 16, 30, 42, 54 and 66 inches). Half of each sample was filtered to remove the algae and other suspended matter. The samples were preserved with 0.8 ml/l concentrated sulfuric acid, as per Standard Methods (34), for future analysis.

The samples were analyzed for COD as soon as time permitted, using the low-level COD procedure outlined in Standard Methods (34). Total nitrogen, ammonia nitrogen and nitrate and nitrate nitrogen analyses were made, every two weeks, on the Auto-Analyzer. Analyses performed on the Auto-Analyzer were standardized with procedures outlined in Standard Methods (34) and results matched within 90% of each other.

Depth profiles of pH, ORP, DO and temperature were made (at 8:00 a.m. and 8:00 p.m.) at the beginning and end of the test period.

3.4 Instrumentation

The various pond parameters were measured with a minimum of instruments in order to simplify analysis of the model pond. The determination of pH and ORP was performed with a Beckman Model N pH Meter. Dissolved oxygen and temperature were measured with a Precision Scientific Company Galvanic Cell Oxygen Analyzer. A six place reflux apparatus was used in the COD determination and the Auto-Analyzer, Technicon Controls, Inc., was used for the determination of the total and inorganic nitrogen.

The Beckman Model N pH Meter: For the measurement of pH and ORP *in situ* at different depths, specially modified electrodes were used with the Beckman Model N pH Meter. To protect the glass electrode from the water, it was enclosed in a four foot length of one inch diameter glass column. A water tight mount for the glass electrode was made from a rubber stopper which was inserted at the lower end of the glass column.

The standard colomel reference electrode was modified to a greater extent. A four foot length of small diameter (1/4 inch O.D.) glass tubing was attached to the refill orifice of the colomel electrode. The upper half of the colomel electrode with the length of glass tubing projecting up, parallel to the axis of the electrode, was imbedded in an epoxy compound and allowed to harden. This arrangement permitted the colomel electrode to be submerged up to depths of four feet without

the water pressure interfering with the transfer of electrolyte (saturated KCl) from the electrode to the test solution. With the glass tube full of saturated KCl solution there would be sufficient head to counteract the hydrostatic pressure of water up to depths of four feet.

A platinum electrode was constructed from a small piece of platinum encased in eopxy. The epoxy provided a permanent and water tight case for the electrode.

The electrodes were attached to the Beckman Model N pH Meter and the pH and ORP readings were standardized against standard buffers. The standard calomel electrode potential, for saturated KCl at 20°C, as referred to a hydrogen electrode is +250 mv. The potential for the standard calomel - platinum electrode system in quinhydrone at 20°C with potassium hydrogen phthalate buffer (pH 3.97) and acetate buffer (ph 4.6) is +473 mv and +437 mv respectively. The platinum electrode in quinhydrone when referred to the standard calomel electrode at 20°C has a potential of +223 mv and +187 mv in potassium hydrogen phthalate buffer and acetate buffer respectively (19). Utilizing the above potentials and equation (1), the pH meter readings with the platinum electrode were converted to ORP potentials.

$$ORP = 60(7 - pH) + a \qquad (1)$$

where:

ORP = Oxidation Reduction Potential

pH = pH meter reading with standard calomel - platinum electrode system

a = constant determined with buffers of known potential

Galvanic Cell Oxygen Analyzer: Dissolved oxygen and temperature measurements were made with a Precision Scientific Company, Galvanic Cell Oxygen Analyzer. The galvanic cell readings were standardized with the Azide Modification of the Winkler Method (34).

Auto-Analyzer: The Auto-Analyzer, Technicon Controls, Inc., consists of instruments (proportioning pumps, digester, colorimeter and strip chart recorder) designed to automatically take a small aliquot of sample, mix it with reagents, digest it and compare the amount of color developed with that of known standards. This instrument is shown in Fig. 4.

The determinations of total-nitrogen (organic-N + NH_3 - N), ammonia-nitrogen and nitrate-nitrate nitrogen were made on the Auto-Analyzer. Each test requires a different manifold and set of reagents. Schematics of the manifolds used are shown in Figs. 5, 6, 7 and 8. The test procedures are given in the Auto-Analyzer instruction manual.

The determination of COD was also attempted on the Auto-Analyzer, but due to the low concentration of COD in the samples, satisfactory results were not obtained with this instrument. Subsequent analyses for COD were made on a six place reflux apparatus using the low-level method outlined in Standard Methods (34).

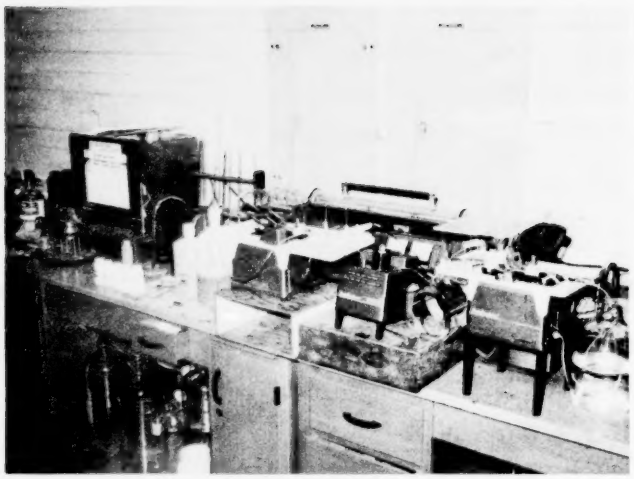


FIG. 4. THE AUTO ANALYZER

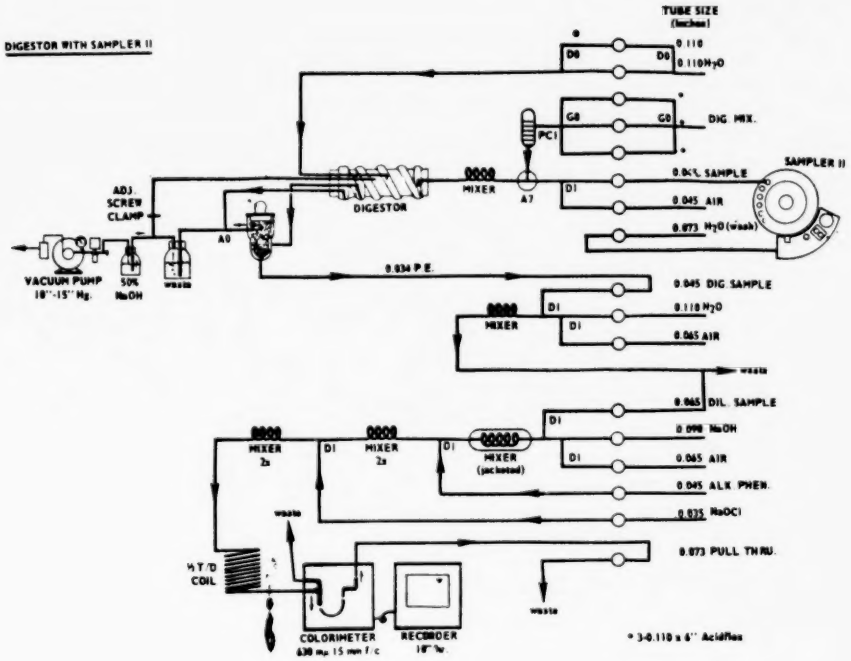


FIG. 5. AUTO ANALYZER MANIFOLD FOR TOTAL KJELDHAL NITROGEN

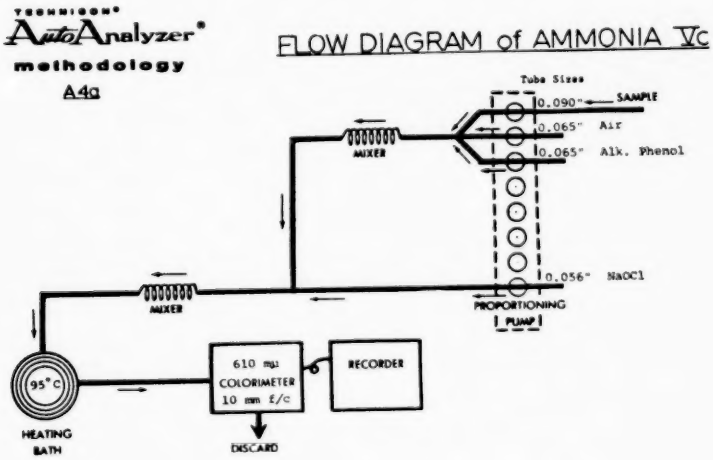


FIG. 6. AUTO ANALYZER MANIFOLD FOR AMMONIA NITROGEN

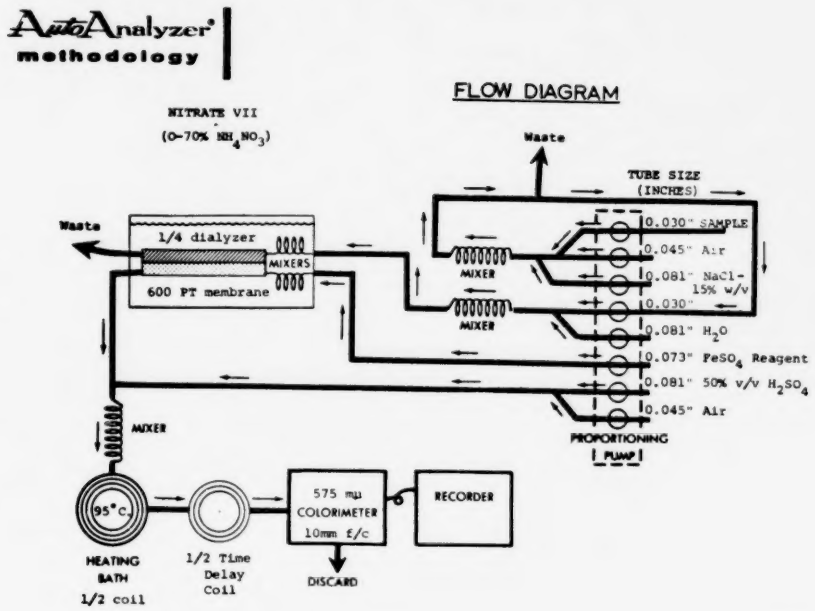


FIG. 7. AUTO ANALYZER MANIFOLD FOR NITRATE NITROGEN

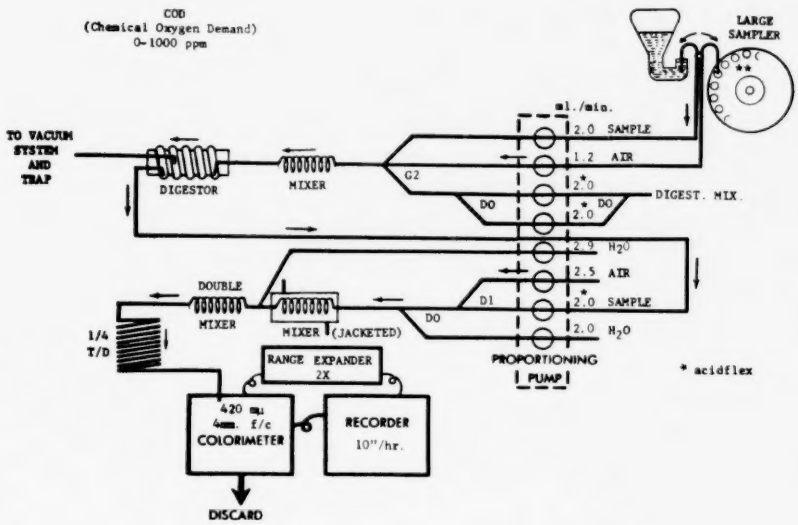


FIG. 8. AUTO ANALYZER MANIFOLD FOR COD

3.5 Acclimation Procedures

In order to obtain an algal-bacterial system operative in the model pond, the pond was seeded with effluent from a facultative-type waste stabilization pond used to treat excess activated sludge. This seed from the Austin pond contained a wide variety of algae, including Actinastrum, Ankistrodesmus, Chlorella, Closterium, Coelastrum, Phacus, Scenedesmus and Staurastrum. Scenedesmus was the most predominant.

To acclimate the seed, enough Starlac was added to raise the COD of the model pond to approximately 350 mg/l. The model was then allowed to remain idle until a noticeable decrease in COD was observed. During this period, the growth of algae was seriously impaired by a relatively thick scum layer that developed on the surface of the pond. It seems the scum was composed mostly of dead Paramecium cells. Directly under the scum layer, swarms of Paramecium could be observed. Apparently this heavy growth of Paramecium was depleting the algae and oxygen quite rapidly. At this point, the stirring mechanism, previously described, was installed.

During the early stages of acclimation, the pond contents turned completely anaerobic and the pH dropped to below 4.0. This condition was believed due to a large amount of acid fermentation brought about by the high concentration of milk wastes which are known to produce lactic acid as well as other acids. To provide a more suitable initial

environment, the contents of the pond were diluted to about 150 mg/l of COD and reseeded with Austin pond effluent.

After it was observed that the algae had established themselves in the pond, daily feeding was initiated. At this point, the predominant algae was still Scenedesmus, although the species diversity had been drastically reduced. By the end of the test period, the predominant species had changed to a blue-green, Oscillatoria, with limited numbers of Euglena and Phacus. An Achromatium - like bacterium with sulfur containing globules was also present. Along with the change in predominant species, a marked decrease in concentration of algal cells was noticed.

IV. EXPERIMENTAL RESULTS

The pond performanced was judged in several different ways. The general characteristics of the pond performance were determined from depth profiles of such parameters as ORP, pH, DO and temperature. From these basic parameters, pond operation could be compared to that of existing facilities. It would also be possible to determine to what extent the pond had behaved in a manner conforming to the general design expectations.

The behavior of organics in general and the several forms of nitrogen (organic and inorganic) was determined from depth profiles of these chemical parameters. Evaluation of the degree of removal of both organic and nitrogenous compounds was made from influent and effluent values of these parameters.

4.1 General Characteristics

Pond operation, as indicated by the ORP, pH, DO and temperature profiles, was satisfactory. The model pond behaved in a manner similar to that observed in existing facilities. The results obtained from the temperature, DO, pH and ORP profiles are summarized in the following paragraphs.

Temperature: Temperature profiles, Figs. 9a and 10a, show the development of a thermocline during the light period (8:00 a.m. to 8:00 p.m.). At the beginning of the experiment, summer conditions

prevailed and a much fuller thermocline developed. Cooler ambient temperatures during the latter phases of the test period did not permit temperatures to be as high as in the initial phase. Throughout the entire duration of the test period, the thermocline completely disappeared during the night hours. The depth of the thermocline varied from 30 cm, during the summer, to 50 cm during the fall.

Dissolved Oxygen: Coinciding with the thermocline, an aerobic layer developed during the day with DO concentrations slightly in excess of 5 mg/l. The aerobic zone was slightly deeper at the end of the experiment, but the DO concentrations were lower as compared to the earlier part of the test period. During the night the pond would be void of dissolved oxygen (Figs. 9b - 10b). The layer of water above the thermocline became oxygenated due to algal photosynthesis, allowing aerobic organisms to flourish in this region. Below the thermocline, the pond remained void of oxygen at all times.

pH: As a result of photosynthesis, a rise in pH can be seen above the thermocline during the day. The rise in pH corresponds to the utilization of carbon dioxide by the algae during photosynthesis. A build up of carbon dioxide during the night is apparent from the drop in pH (Figs. 9c and 10c) at this time. The accumulation of carbon dioxide is a direct result of combined algal and bacterial respiration during the night hours. The pH curve has a pattern similar to that of the thermocline.

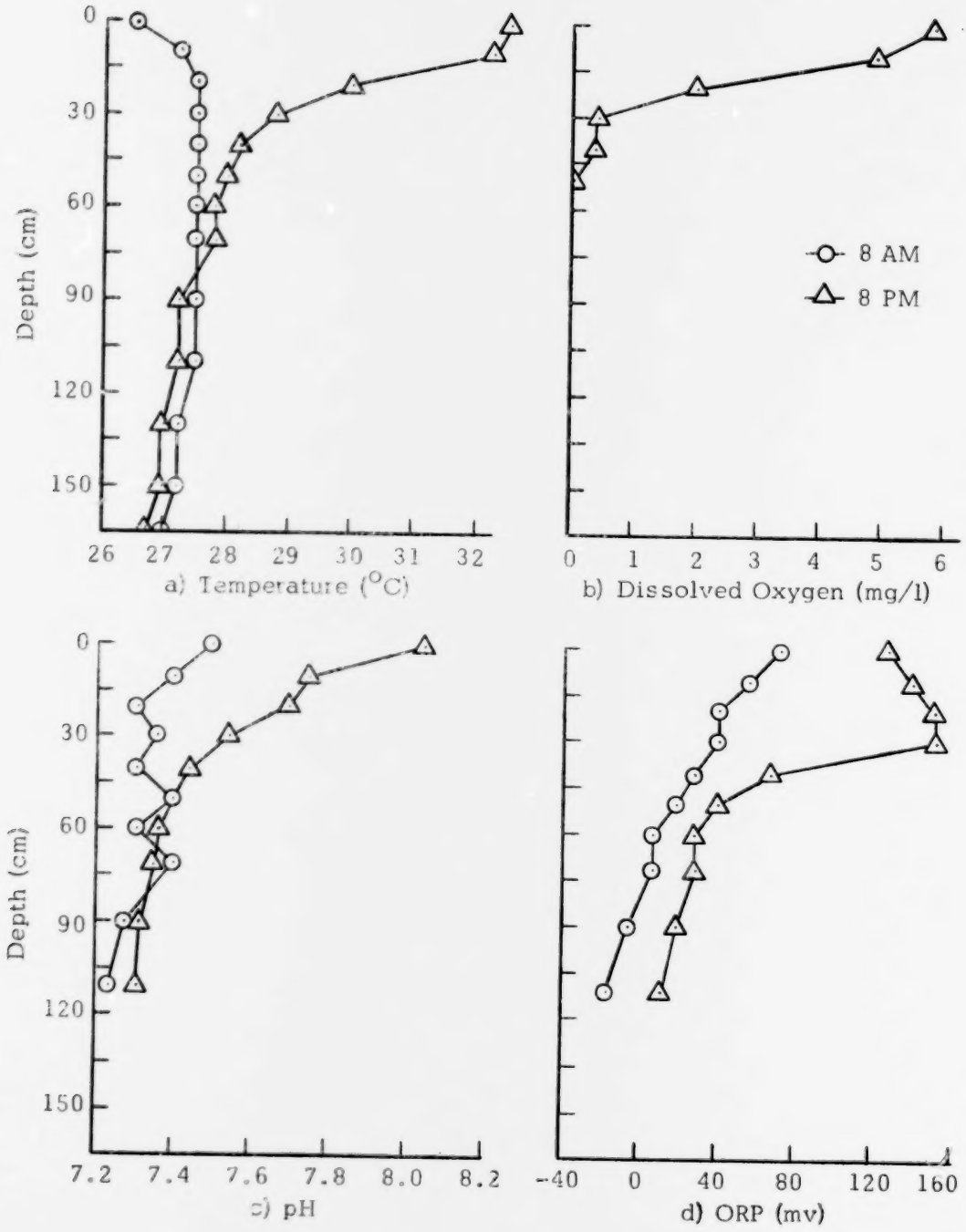


FIG. 9. DEPTH PROFILES AT BEGINNING OF TEST PERIOD (JULY 12, 1966)

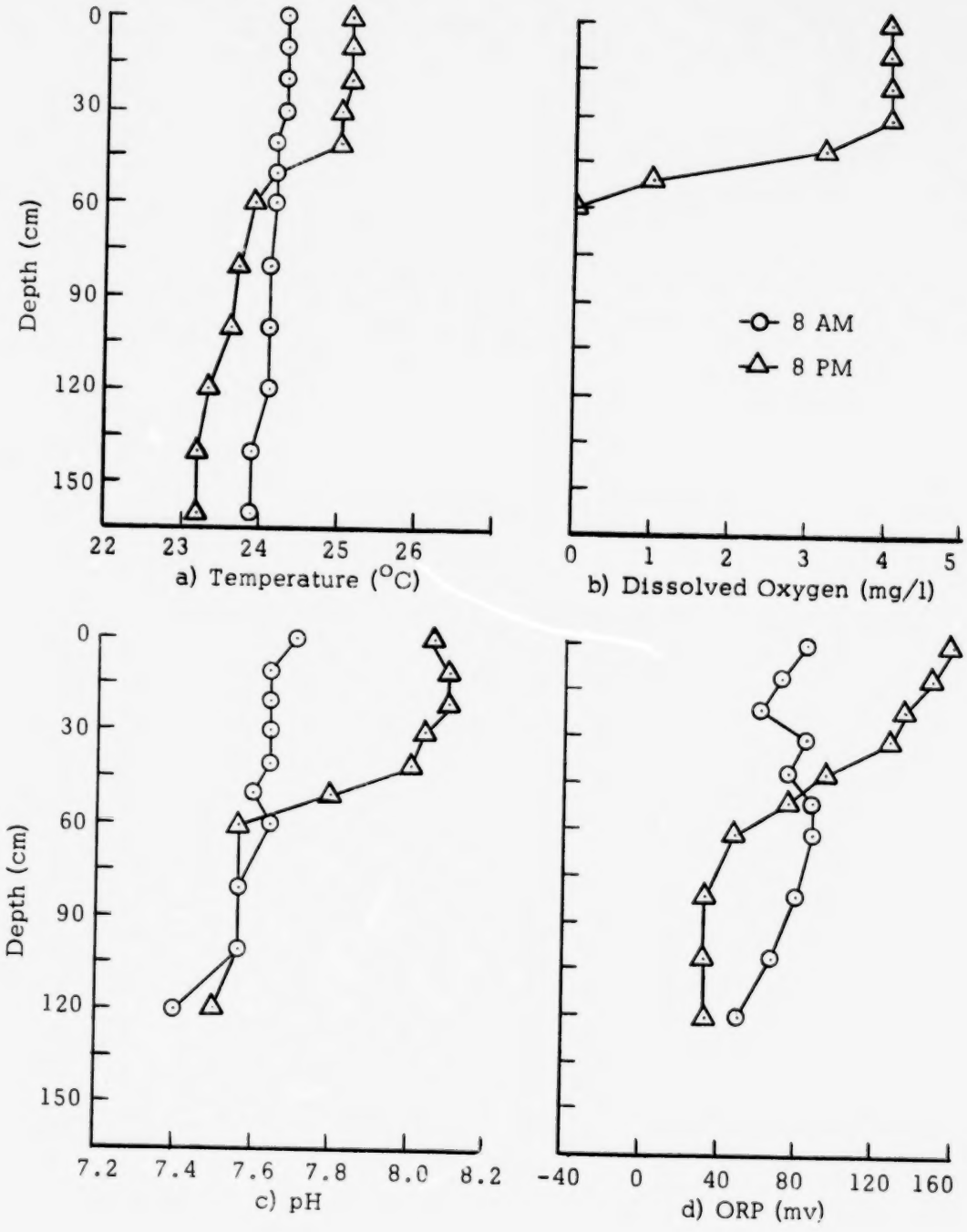


FIG. 10. DEPTH PROFILES AT END OF TEST PERIOD (OCTOBER 15, 1966)

Oxidation Reduction Potential: The oxidation reduction potential measurements were made to determine the oxidizing or reducing character of the pond contents. The ORP curves follow the same pattern as the temperature and pH curves (Figs. 9d and 10d). All the values obtained, however, were positive as referenced to the hydrogen electrode. Since the zone below the thermocline is devoid of oxygen, it would be reasonable to assume that reducing conditions prevail. The ORP measurements indicate, on the other hand, that oxidation processes predominate throughout the pond at all times. Since the model is made of iron, small cracks in the protective fiber glass coating could provide small amounts of ferrous ions to the solution. The oxidation of ferrous to ferric ions has a highly positive electrical potential (+771 millivolts) and may have contributed to the positive oxidation reduction potentials measured in the pond.

4.2 Organic Loading and Removal

The organic loading applied to the pond was set at 50 lbs BOD_5/acre/day as stated in section 3.2. In order to determine the oxygen demanding characteristics of Starlac, a Biochemical Oxygen Demand curve was obtained for a 1 g/l solution of Starlac. The biological seed used for the test was withdrawn from the aerobic portion of the model pond. The resulting curve is shown in Fig. 11. The ratios of BOD_5/Starlac and BOD_5/COD, respectively, were 0.65 and

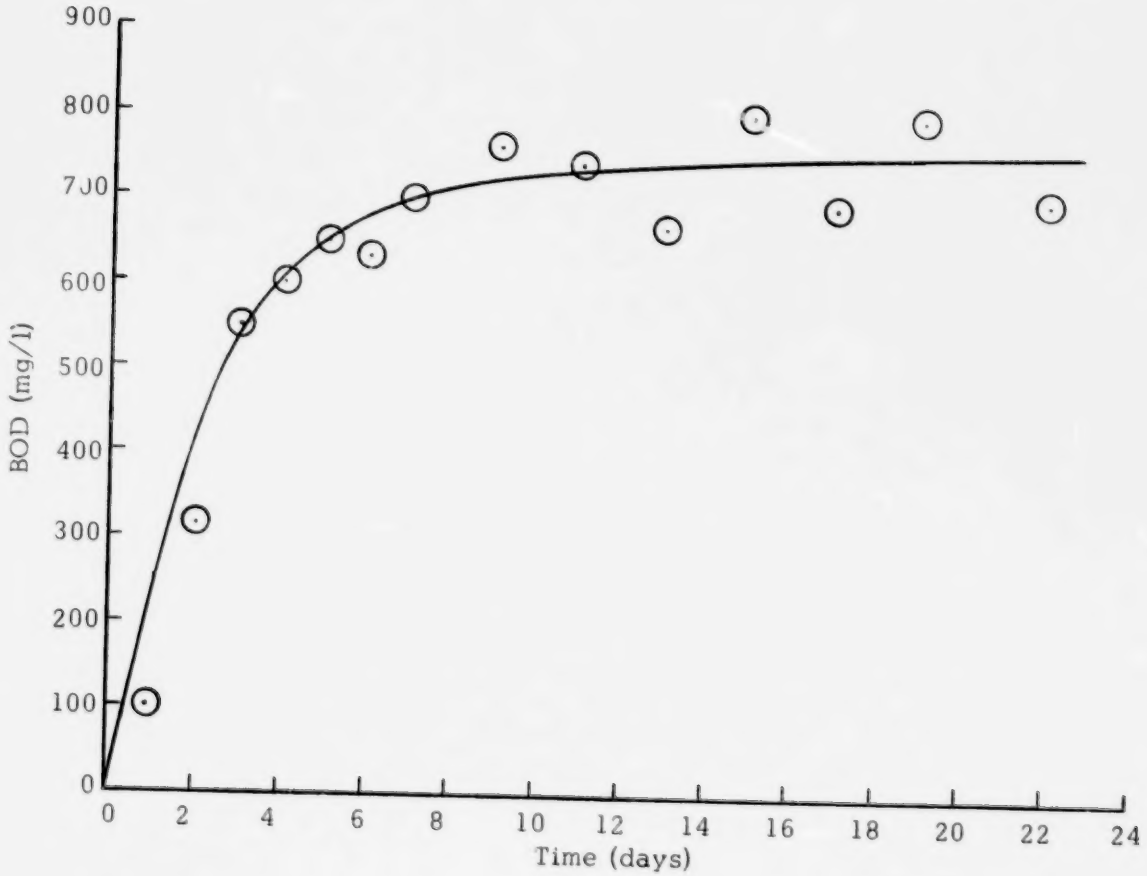


FIG. 11. BOD CURVE FOR A ONE GRAM/LITER SOLUTION OF STARLAC

0.75 at 26.5°C. Converted to 20°C, the BOD_5/Starlac and BOD_5/COD ratios, respectively, were 0.59 and 0.68.

Once the BOD characteristics of the milk waste had been correlated to COD, the carbonaceous content of the pond water was determined by means of the COD test since it is a much quicker and convenient measurement than BOD. Figs. 12 and 13 show the COD of the influent, effluent and of the individual sampling stations during the test period. The computed value for the influent COD is 105 mg/l, and is shown as a straight line in Fig. 12. Actual influent COD values obtained analytically varied somewhat from that shown in Fig. 12, but the variation was within the accuracy of the analytical technique.

An estimate of the concentration of organisms can be made by comparing the filtered and unfiltered COD values at each sampling station. In general, the concentration of organisms was low throughout the test period. One exception to the low concentration of organisms is seen early in the test period (Fig. 12), when the pond was allowed to remain idle for one day. The algae were able to build up, during an extra day, to 203 mg/l of COD, most of which was actual cell COD in suspension. The increased growth of algae on the available substrate proved that the medium was not lacking in nutrients, but the low yield of algae, during the experiment, indicated an inadequacy in detention time. The detention time of the model pond was not increased since it was felt that 21 days retention was representative of a number of existing

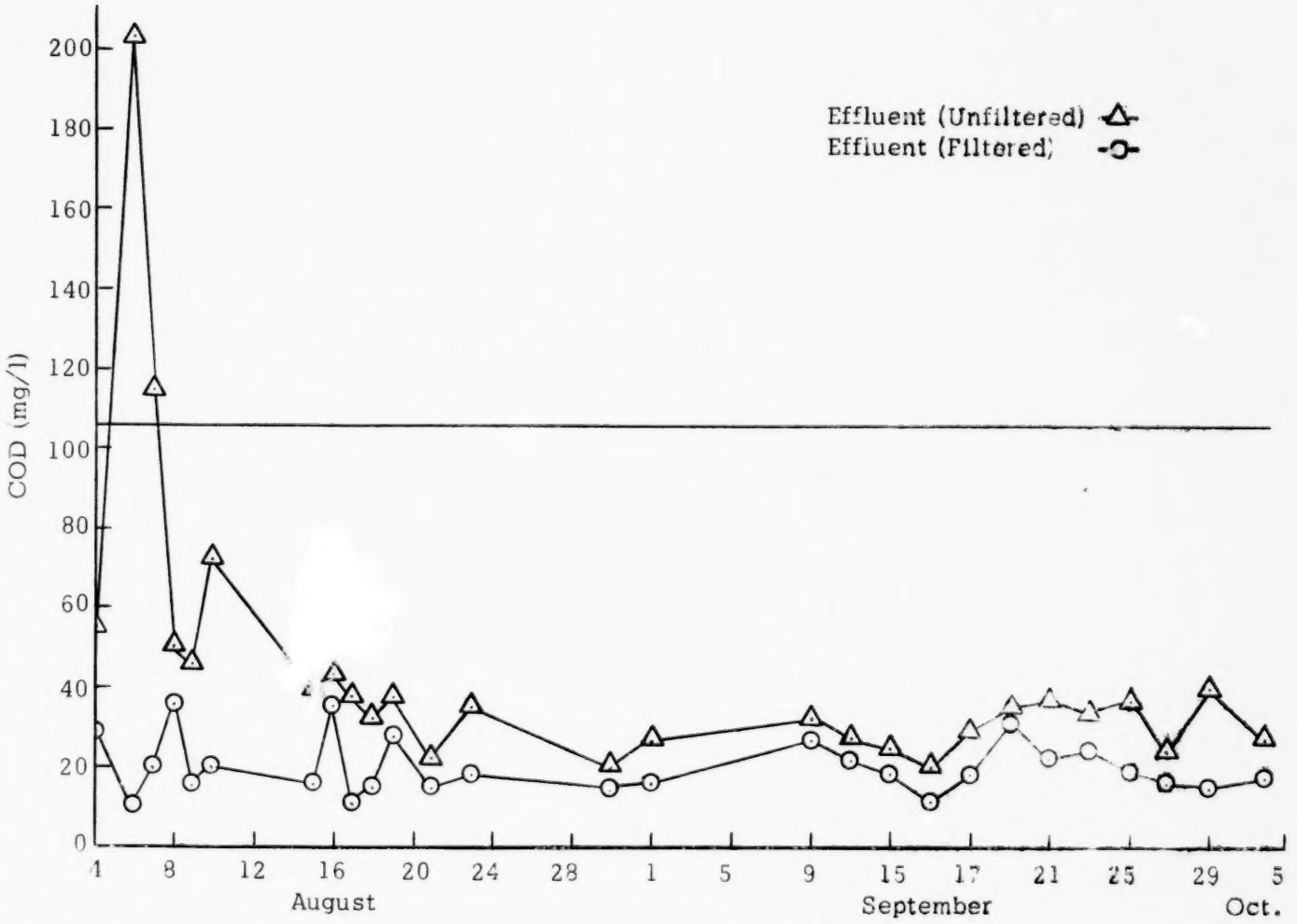


FIG. 12. INFLUENT AND EFFLUENT COD VALUES

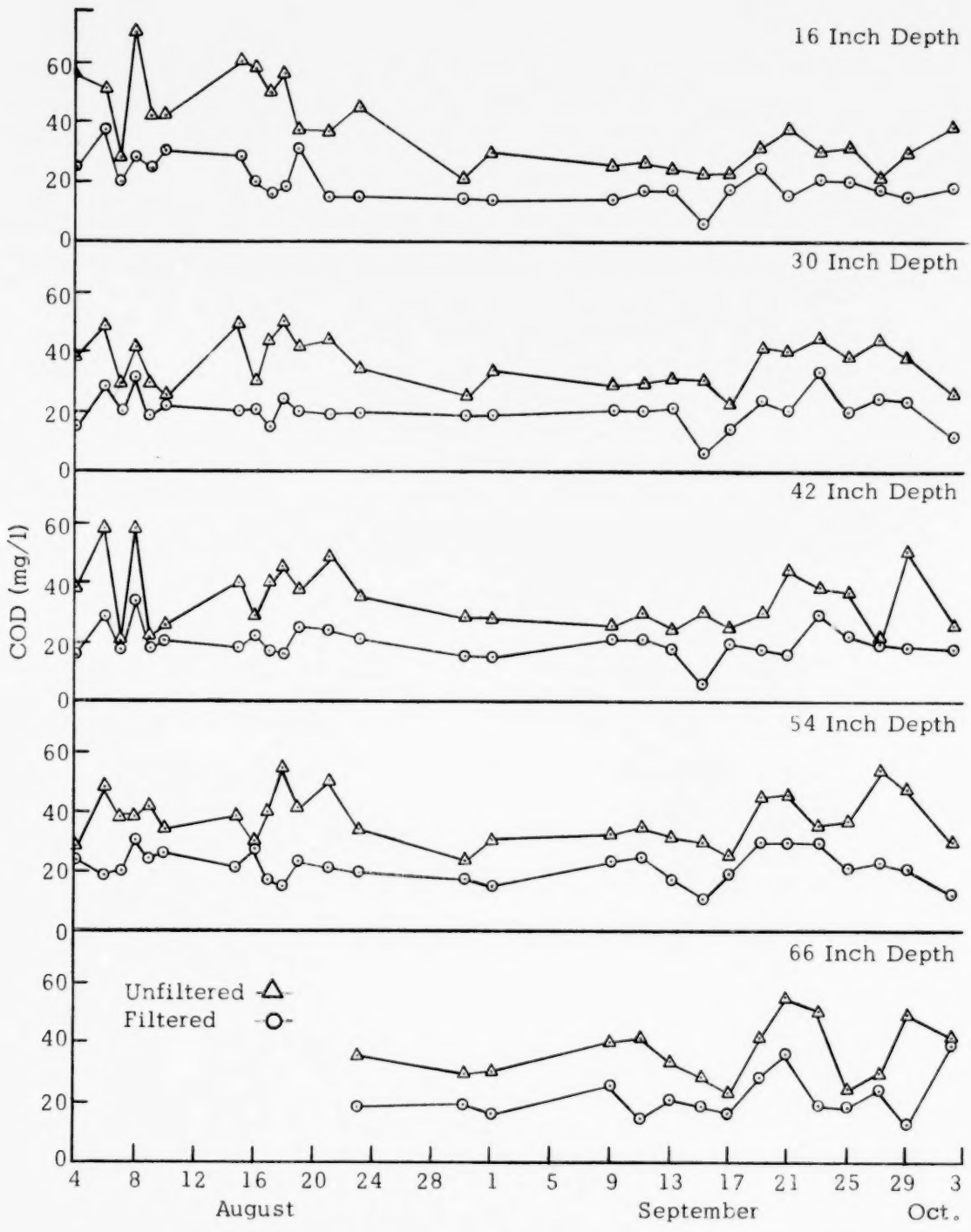


FIG. 13. COD VALUES AT THE FIVE SAMPLING STATIONS

operations. The organic load on the pond was, also, too low to warrant an increase in retention time.

Milk, being a readily oxidizable substrate, was essentially removed from solution within the first 10 inches from the inlet of the pond. Depth profiles of COD for some typical test days are shown in Fig. 14. These show very little variability of COD with respect to depth.

The accidental discovery of a black flocculant material forming a sediment layer on the bottom of the pond, prompted further analysis at the end of the experiment. It was determined that the layer of material, comprised of organic debris, was approximately one inch thick. The COD of the material was found to be on the order of 11,670 mg/l. Quite a large portion of the algal and bacterial population of the model pond apparently settled to the bottom where they underwent anaerobic decomposition. A considerable amount of sulfides were present as was evidenced from the release of hydrogen sulfide upon lowering the pH of the sample and the black color of the sediment material.

The COD removal efficiency of the model pond, during the two month test period, was calculated at 85%. If the algal cells found in the pond effluent are included in the material balance, the COD removal efficiency drops to 71%. Taking into consideration that the COD accumulated in the bottom sediment, although removed from the

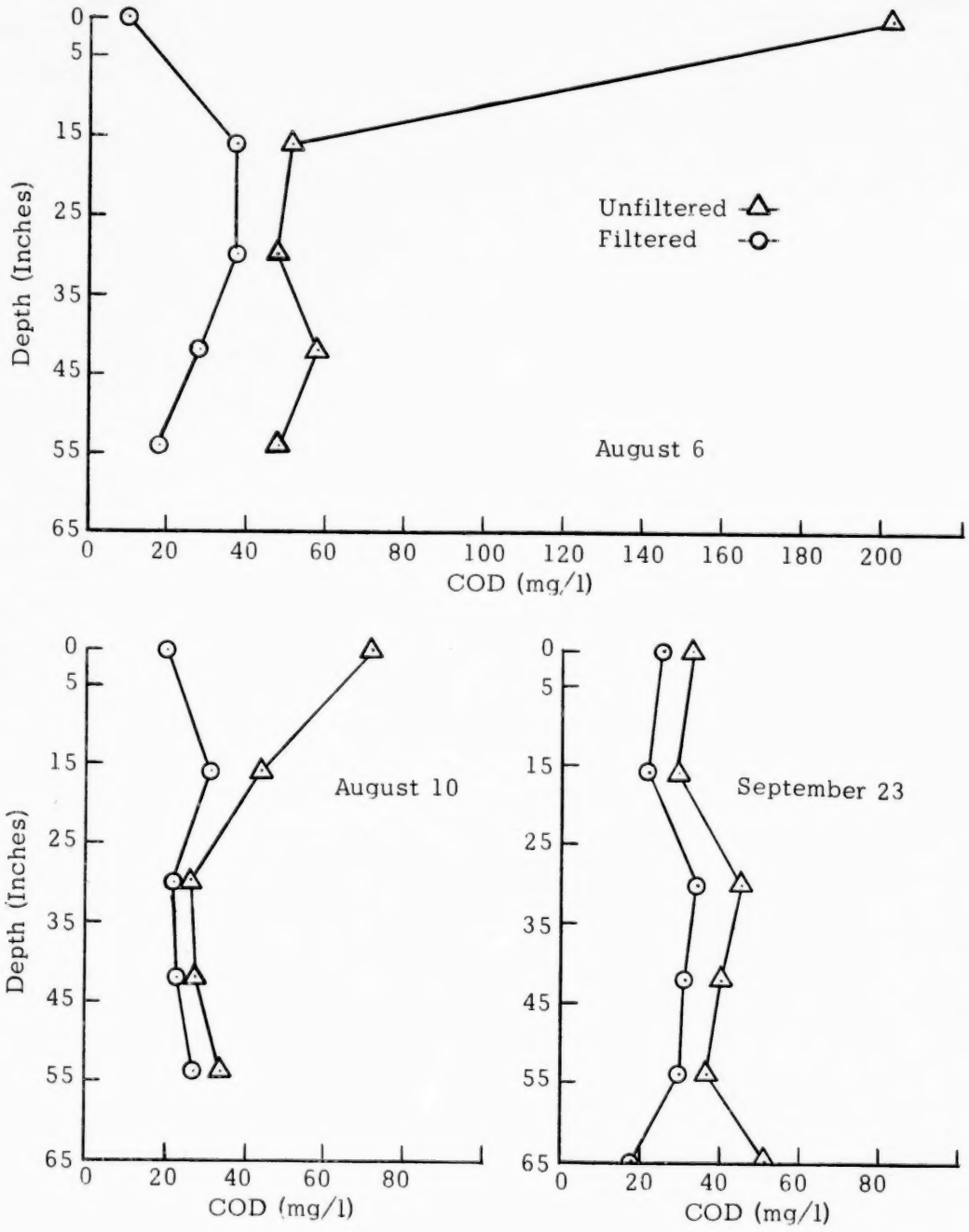


FIG. 14. TYPICAL COD PROFILES

effluent, has not been lost from the system; a recomputed value for the organic removal efficiency stands at 45%. A material balance of the COD in the pond is performed in Appendix B.

4.3 Nitrogen Loading and Removal

The nitrogen content of the milk waste solution provided a loading of 5.3 lbs N/acre/day, which gave a ratio of $BOD_5/N = 10/1$. The nitrogen loading was sufficient for growth and hence, no additional nitrogen source was added to the substrate. Under the assumption that protein contains 16% nitrogen, the concentration of nitrogen in the influent waste was calculated at 6.1 mg/l. Analysis of the waste yielded values well within analytical error of the computed concentration.

Figures 15 and 16 show the variation of total-nitrogen, both suspended and in solution, and ammonia during the test period for the effluent and other sampling stations. In general, the total-nitrogen concentration did not fluctuate widely. The effluent nitrogen concentration suffered a sharp increase similar to that of the COD at the beginning of the test period. It is interesting to note that the increase in total-nitrogen was almost exclusively in the suspended fraction without an apparent decrease of nitrogen from solution. It is entirely possible that some of the algae were fixing nitrogen from the atmosphere, although this does not generally occur unless nitrogen is in limiting amounts.

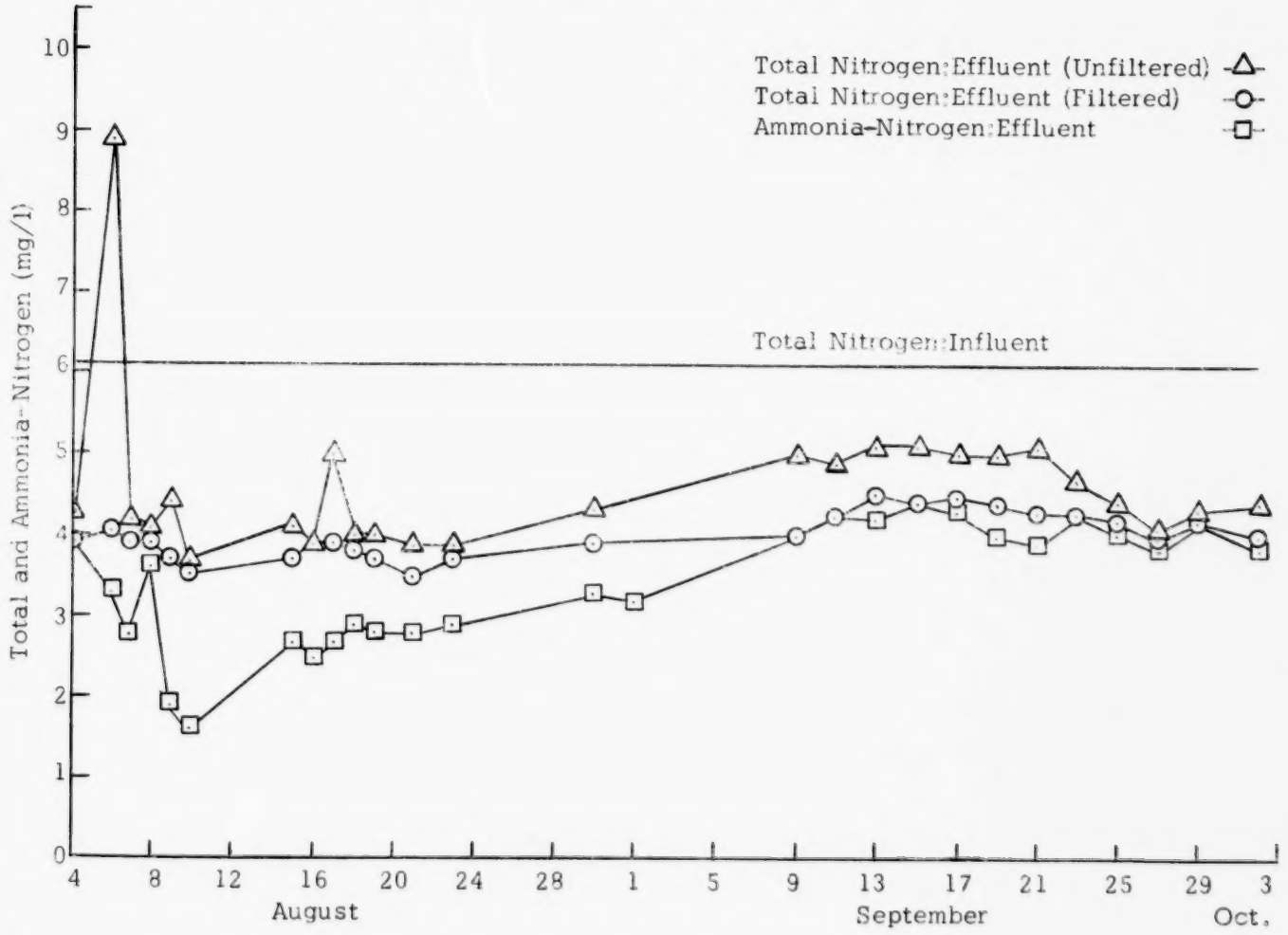


FIG. 15. INFLUENT AND EFFLUENT TOTAL AND AMMONIA-NITROGEN VALUES

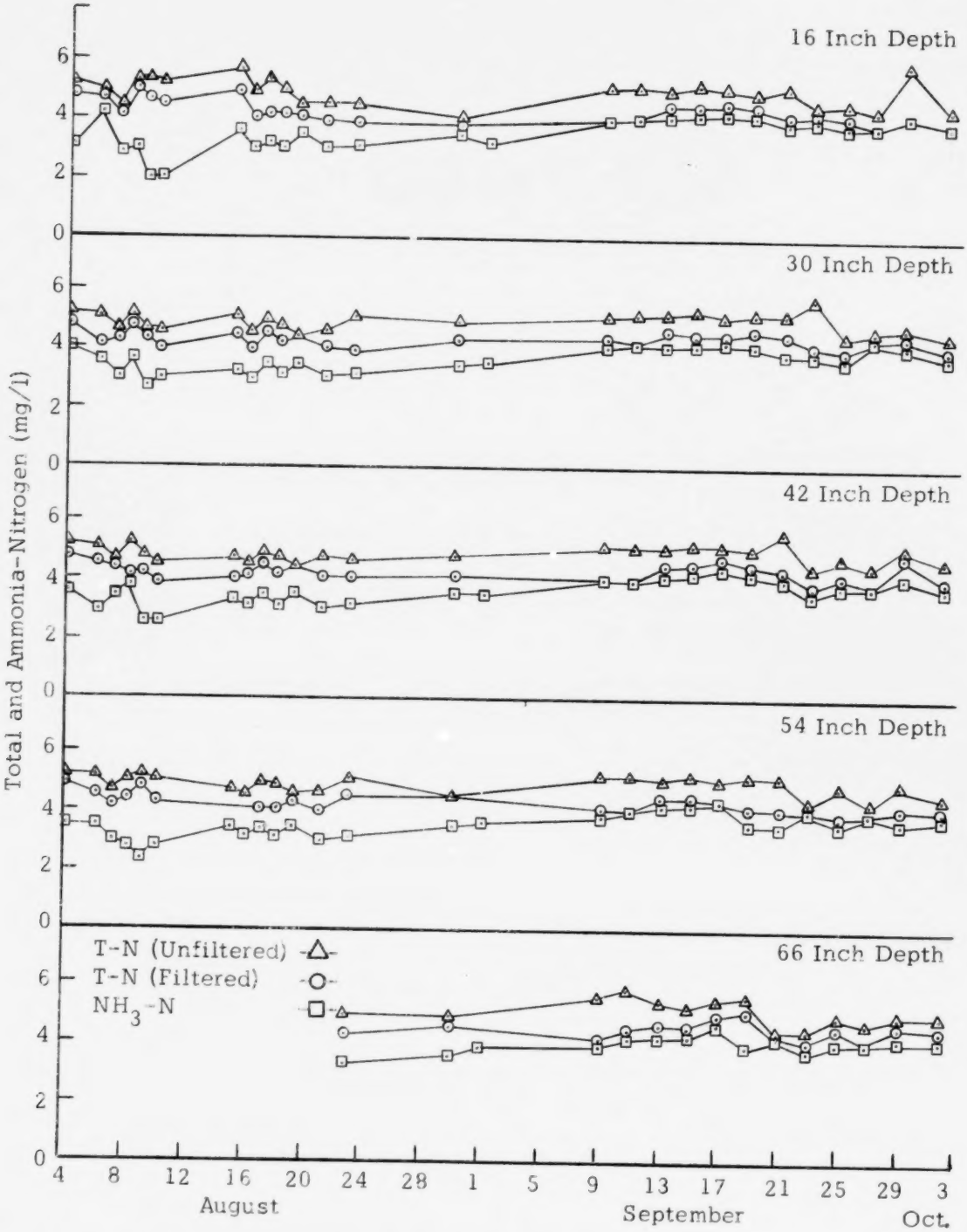


FIG. 16. TOTAL AND AMMONIA-NITROGEN AT THE FIVE SAMPLING STATIONS

Ammonia concentrations are also plotted in Figs. 15 and 16. The variation of ammonia is insignificant in most cases and seems to follow the curve for total dissolved nitrogen reasonably close. In fact, ammonia is often the only component of the soluble nitrogen fraction and, always making up the bulk of the nitrogen in solution. The relative concentration of ammonia also made up the major portion of the nitrogen in the whole system. The organic material entering the pond was quickly utilized with the conversion of organic nitrogen to ammonia. The ammonia remained fairly constant throughout the depth of the pond as seen in Fig. 17.

Although, the loading was purposely kept low to enhance the conditions for nitrification, nitrates were never found above a trace (<0.1 mg/l). The organic loading may have been low enough for nitrifying organisms to flourish, but it is believed that the amount of nitrogen present in the system was probably too low. Low nitrogen concentration coupled with insufficient oxygen tension may have been enough to inhibit nitrification.

The black sediment that accumulated on the bottom of the model pond during the experiment was found to contain a high concentration of nitrogen. The sediment contained 360 mg/l of nitrogen, which gave a ratio of COD/N in the sediment of 32.5/1. The amount of nitrogen, although not at an optimum, was in sufficient amount to support active bacterial growth. An active bacterial population in the sediment is

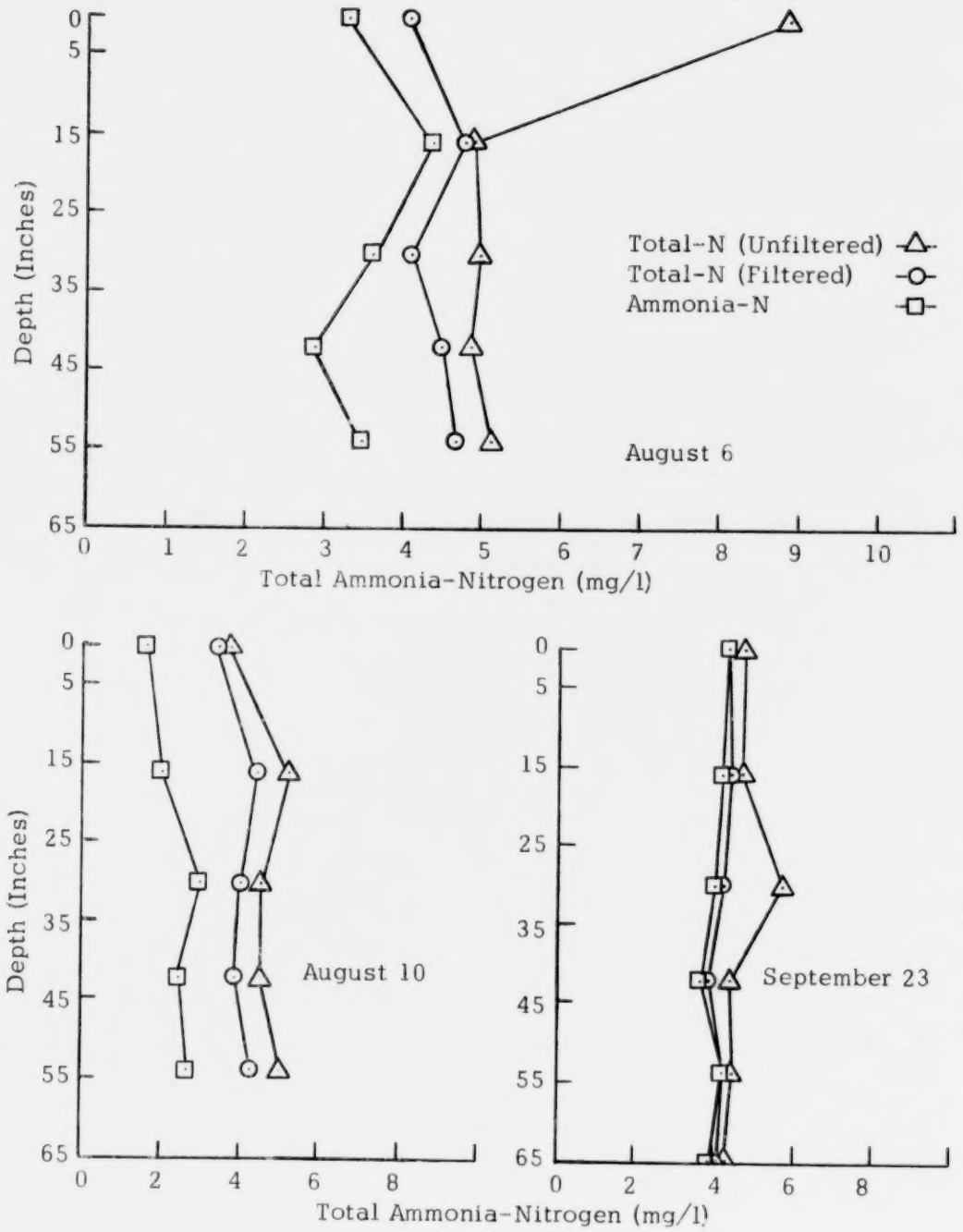


FIG. 17. TYPICAL NITROGEN PROFILES

evidenced by the fact that most of the organic nitrogen present is in the solid fraction, 360 mg/l as opposed to only about 3 mg/l in the liquid fraction. The remainder of the nitrogen in the liquid fraction, 5 mg/l, is in the form of ammonia.

Denitrification was not found to occur since nitrates were nonexistent, at anytime, during pond operation. Loss of nitrogen from the system, however, did take place. A nitrogen balance of the system resulted in a fraction, 29.9%, of unaccountable nitrogen. From the nitrogen balance it was also determined that the pond accomplished the removal of 44% of the influent nitrogen from the effluent. The removal of nitrogen from solution was slightly higher at 52%. A material balance of the nitrogen in the pond is performed in Appendix B.

V. DISCUSSION

The results obtained indicate the model pond operated satisfactorily in most respects although, some difficulty was encountered in maintaining a large algal population. The low algal density resulted in a poorly oxygenated zone above the thermocline. The lack of dissolved oxygen above the thermocline during the night hours apparently inhibited nitrification. Hence, the effect of depth on nitrification and denitrification could not be studied. Total-nitrogen removal, although not sufficiently high, was representative of pond systems reported in the literature. The results obtained, however, seem to indicate that a pond, under proper conditions, should be able to remove large quantities of nitrogen from solution. Even if denitrification does not take place, most of the organic nitrogen will be converted to ammonia through bacterial action. Once in the form of ammonia, nitrogen can be adsorbed onto the soil to some extent, although the primary mechanism would be through incorporation into algal cell material. The problem of removing the algae from the effluent still remains to be solved.

5.1 General

An excellent picture of the pond performance was obtained from the temperature, dissolved oxygen, pH and oxidation reduction potential profiles. These four parameters corroborate the existence

of a thermocline which disappeared during the 12 hour period of darkness. A permanent thermocline would have been more desirable since it is more representative of conditions in ponds when they have a thermocline. That is to say that thermoclines have seasonal variations but they are not known to vary drastically during a 24 hour period. The disappearance of the thermocline in the model pond was due to the fact that the sides of the tank were exposed to the room environment. Despite the large amount of heat absorbed at the water surface from the light hood, heat was quickly dissipated through the large area provided by the tank walls. In an actual pond, the situation would be different because the earth forming the sides and bottom of the pond serves as a reservoir of heat. Heat losses to the earth are much more gradual and make the pond temperature less dependent on the air temperature.

Dissolved oxygen never reached significant proportions and was in part responsible for the inhibition of the nitrifying bacteria. Under normal conditions dissolved oxygen concentrations could have easily reached supersaturation conditions (15-20 mg/l DO). On several occasions, a glass carboy of the pond effluent was allowed to stand near a window in the laboratory. After a few days under these conditions, a dense algal growth was noted and measurement of dissolved oxygen revealed concentrations in excess of 30 mg/l. Observations made after prolonged periods of darkness revealed that the concentration of dissolved oxygen never dropped below 20 mg/l. Addition of moderate

amounts of milk waste resulted in more profuse algal growth for a limited period (one or two weeks) after which most of the algae disappeared except for those attached to the sides of the carboy. At this point, the dissolved oxygen concentrations were noted to be substantially below normal and the cultures discarded. It is most unfortunate that a more detailed study of the effluent cultures was not conducted but their sole purpose had been to see if algae were capable of growth in the pond water. Once it was established that algae could grow well in the pond water, other reasons were sought for their poor growth within the model pond.

The depth profiles for pH and oxidation reduction potential also provided a measure of the algal and bacterial activity. The values obtained for pH were within the optimum range for both algal and bacterial growth (pH 7 to 8). The variation in pH with depth was also as expected, with the higher values in the oxygenated zone due to carbon dioxide uptake by the algae. On the other hand, ORP values were not at all as expected. Although, the shape of the curves was as anticipated with the larger values in the aerobic zone, the absence of negative ORP values below the thermocline, in the zone devoid of oxygen at all times, was an unpleasant surprise. As stated in Sec. 4.1, the oxidation of ferrous to ferric ions offers a possible explanation. Iron in the ferrous form can exist only in the absence of oxygen and the ferric form is almost completely insoluble. In water containing

CO_2, iron in the ferrous form goes into solution as ferrous bicarbonate, however, if O_2 is present, oxidation to insoluble ferric hydroxide takes place (32). The pond water was not tested for the presence of iron, but Austin tap water is known to contain approximately 0.03 mg/l of iron. The concentration of iron in the model pond could not have been much higher since it was not observable as a precipitate in the pond effluent. Small amounts of iron, however, could have caused, in part, the shift of the ORP curve to the positive potential. In a dilute and complex system, such as the pond water, low concentrations of iron would, understandably, cause the potential to reach only a fraction of the +771 mv potential attainable with the Fe^{2+}/Fe^{3+} half cell reaction. It would follow then, that the maximum value of +170 mv recorded for the pond is entirely reasonable. Also, at such low concentrations as were assumed present, aside from the fact that most of the iron present was precipitated as $Fe(OH)_3$ in the presence of O_2, no toxic effects should be noticeable on the algae.

5.2 COD Removal and Algae

The removal of COD within the pond was quite effective. The COD of the effluent was consistantly low, averaging out to about 20 mg/l in solution. It is practically impossible to obtain lower COD concentrations when using biological systems since lysis of the micro-organisms continually releases organic carbon into solution. Hence, it can be assumed that the bacteria within the model pond were

functioning properly and capable of withstanding a higher organic load without an appreciable loss in COD removal capacity.

The algae fix carbon dioxide produced through bacterial metabolism and, upon cell lysis, also release a substantial amount of carbonaceous cell material into solution. Autotrophic algae can also assimilate some organic substances and incorporate them into cell material. A net reduction of COD from solution would not be expected from the action of algae alone. In the cases encountered during this study (Figs. 14a and 14b), when algae concentrations appeared above normal, the additional reduction in soluble COD was due, most likely, to increased bacterial activity possible from the additional oxygen present.

From the above discussion, it can be seen that the removal of carbonaceous material from solution is accomplished through the combined action of bacteria and algae. The bacteria perform the oxidation of organic carbon to CO_2 and water. Algae provide the oxygen necessary for bacterial respiration and for the prevention of obnoxious odors originating from anaerobic decomposition of organic wastes.

5.3 Bottom Sediments

The bottom deposits in the model pond turned out to be a reservoir of organic material and precipitated inorganics. The presence of a large amount of sediment explains the rapid removal of organic material from the influent waste solution. Almost 28% of the COD

and 16.5% of the nitrogen entering the system accumulated in the bottom sediment. Although the material in the sediment was not entirely lost from the system, the sediment was one of the factors contributing in the removal of COD and nitrogen from the waste water and can be considered an asset of the pond.

Due to the black nature of the sediment, plus the fact that hydrogen sulfide was given off when a sediment sample was acidified, it is reasonable to assume that the sediment contained substantial amounts of ferrous sulfide and ferric hydroxide. The amount of iron in the tap water was not enough to give rise to such a large quantity of precipitate which indicates a substantial amount of iron was coming off the sides of the model pond. The concentration of iron in the water was, apparently, insufficient to inhibit algal growth as borne out by the fact that algae grew well in the effluent if it was allowed to stand for a few days. Algae were also observed alive in samples taken from the bottom of the pond where the concentration of iron was apparently the highest.

5.4 Nitrification and Denitrification

Since nitrates and nitrites did not appear in appreciable amounts during the test period, the nitrifying characteristics of the pond could not be studies beyond the fact that: under the test conditions of the model pond, nitrification was inhibited. Nitrates are utilized by algae only after ammonia has been reduced to concentrations below 1.0 mg/l.

Since ammonia was present in concentrations on the order of 4.0 mg/l, it would have been most unlikely that the algae assimilate any nitrates produced in the oxygenated zone. Had there been production of nitrates during the daylight hours, these would have undergone denitrification in the oxygen lacking conditions of the subsequent darkness period.

Denitrifying organisms are facultative anaerobes in contrast to the strictly aerobic nitrifying bacteria. Due to their ability to grow under both aerobic and anaerobic conditions, denitrifying bacteria had a better chance of surviving in the changing environment near the surface of the model pond. As pointed out in Sec. 2.1, the presence of free oxygen inhibits denitrification almost completely. Therefore, it may have been possible for denitrifying bacteria to exist throughout the model pond, but denitrification could not have taken place in the oxygenated surface zone, the only place where nitrification had a chance of occuring.

Most of the nitrogen in solution was found to be in the form of ammonia. A high degree of ammonification is indicative of an active bacterial population with a high turnover of nutrient materials. Nitrogen fixation could increase the ammonia concentration of the pond but, as it was, nitrogen concentrations were not low enough to stimulate nitrogen fixation. In an open system, such as the model pond studied, nitrogen fixation cannot be determined unless it occurs in amounts large enough to result in a net increase in the nitrogen content of the system.

From a nitrogen balance of the system, it was found that approximately 29.9% of all the nitrogen entering the pond in the milk waste apparently left as gaseous nitrogen. The biological mechanism that resulted in the loss of nitrogen is not known although the possibility of denitrification has not been completely ruled out. The existance of an unknown mechanism where N_2O and N_2 are produced may also be possible but this is not likely. Although ammonia is a highly soluble gas, small amounts of it could have possibly escaped the system.

In an attempt to correlate COD removal with total nitrogen removal, Figs. 18 and 19 are presented. In Fig. 18 the plot is developed for removal of both parameters from solution, whereas, in Fig. 19 the removal of COD and total nitrogen from the effluent as a whole (both soluble and suspended fractions) is shown. No significant differences are apparent, except at the beginning of the test period when an accumulation of algae resulted in above normal values of COD and nitrogen. As previously mentioned, the increased growth of algae was a direct result of postponing feeding operations for one day. The increased detention time from the lack of effluent during one day allowed the algae more time for growth resulting in abnormally high amounts of algae in the following day's effluent. From the above, it is reasoned that the detention time was responsible for the sparse algal growth and not the presence of an inhibitory substance in the pond water. Observation of the model pond performance has led to

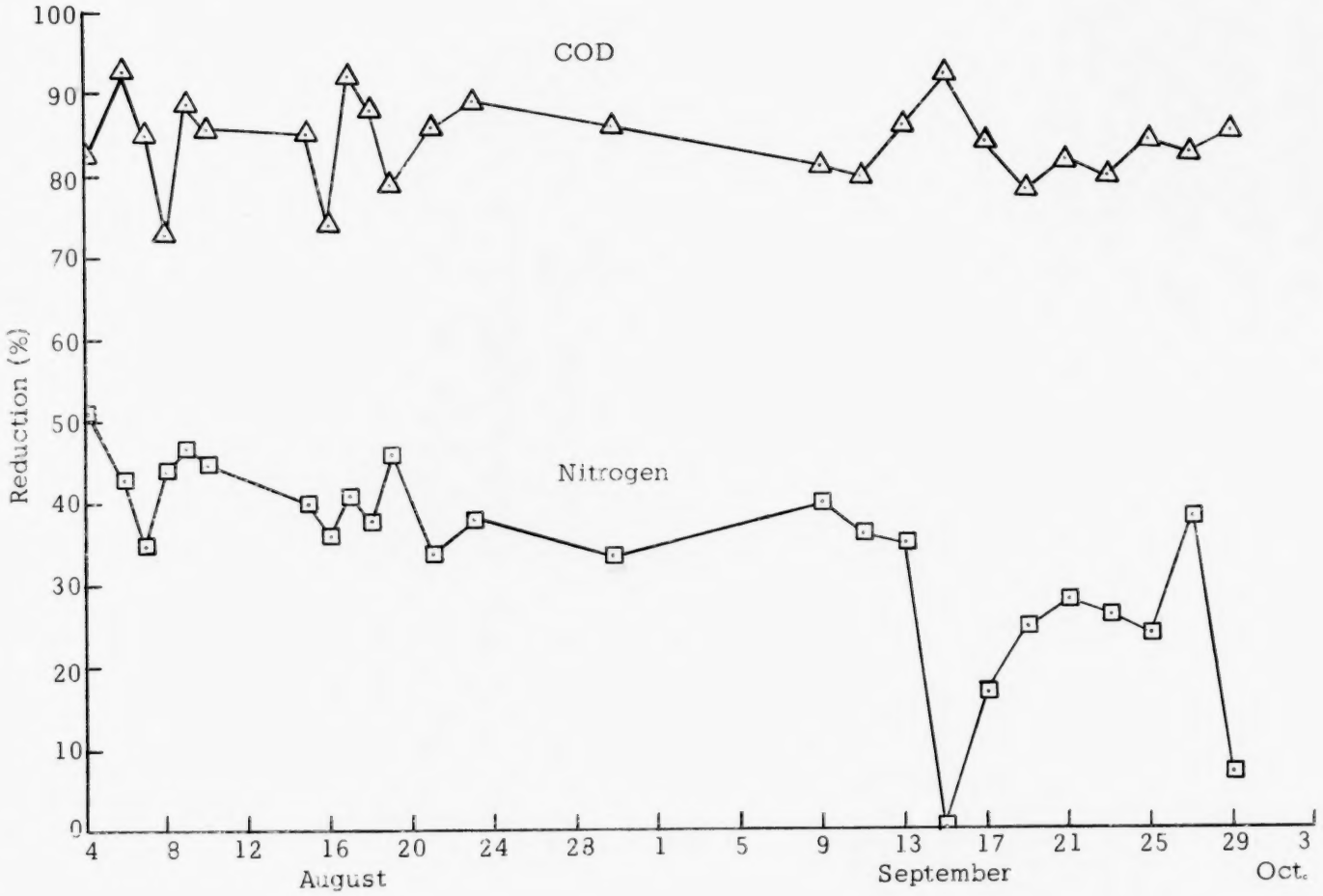


FIG. 18. REMOVAL FROM SOLUTION OF COD AND NITROGEN

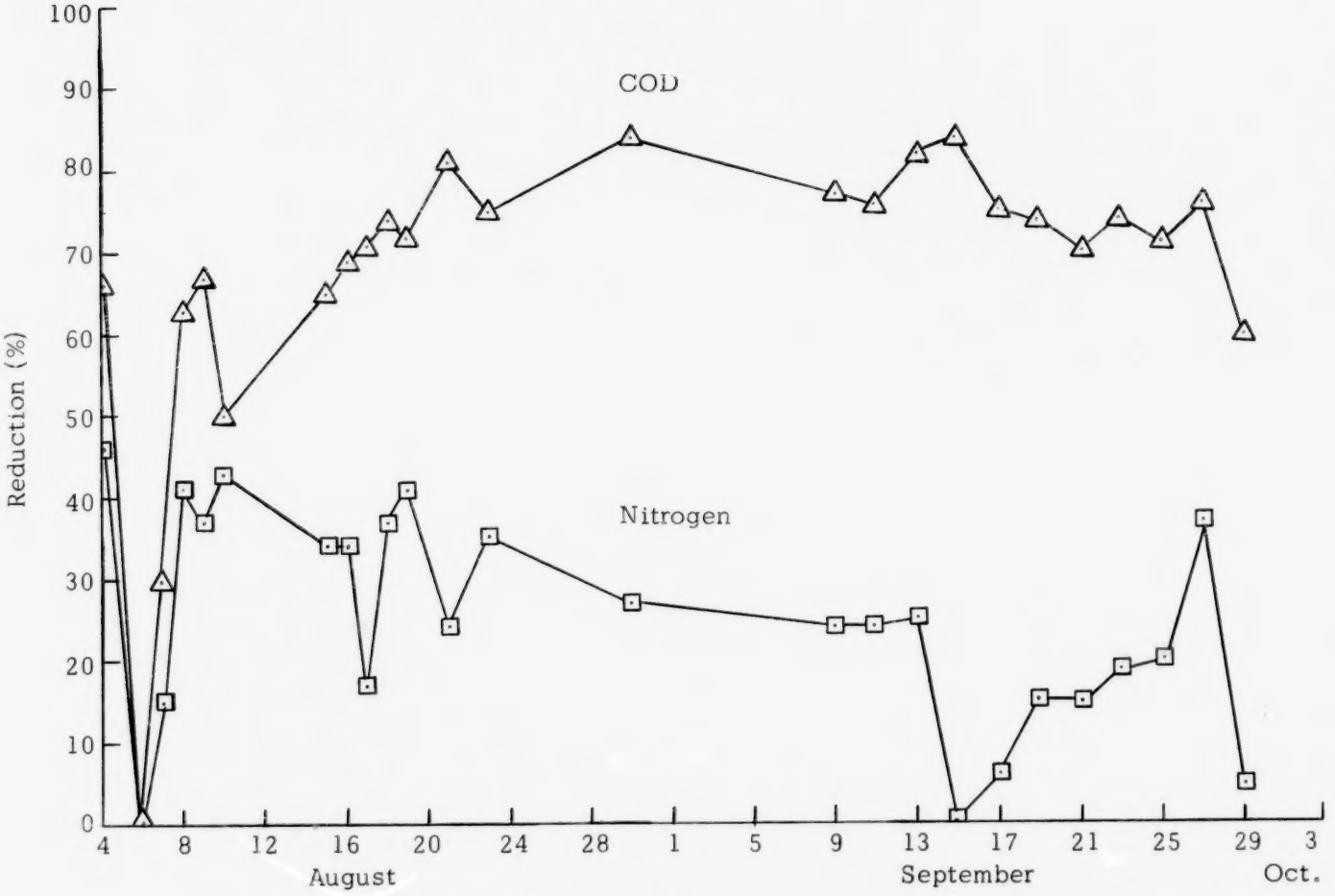


FIG. 19. REMOVAL FROM EFFLUENT OF COD AND NITROGEN

the belief that a model scaled down in area only is not adequate for proper algal growth during detention periods not exceeding 30 days. The reason is that algae grow in a limited zone near the surface and, if the detention period is short enough to remove this zone in one day's effluent, the algae are essentially washed out of the system. This seems to be the case in this study.

In order to compare nitrogen removal efficiencies with the nitrogen content of the algae in the effluent, the amount of nitrogen, as a percentage of COD, in the suspended fraction of the effluent is given in Fig. 20. No correlation is evident from comparison of Figs. 18, 19 and 20. During a period of approximately 25 days, the nitrogen content of the suspended cell material in the effluent increased above normal but an increased removal of nitrogen during this period is not evident. The possibility exists that nitrogen fixation provided the extra nitrogen.

A plot was made (Fig. 21) of the variation in percent removal from solution of COD and total-nitrogen with respect to the amount of solids in the effluent, as determined by the difference in COD of the filtered and unfiltered samples. COD removal from solution seems to increase slightly with increased solids. The increased COD removal is a direct result of the increased microbial activity although, larger removals could be accomplished if the algae were not present since they do not essentially contribute to the removal of organics. In Fig. 22,

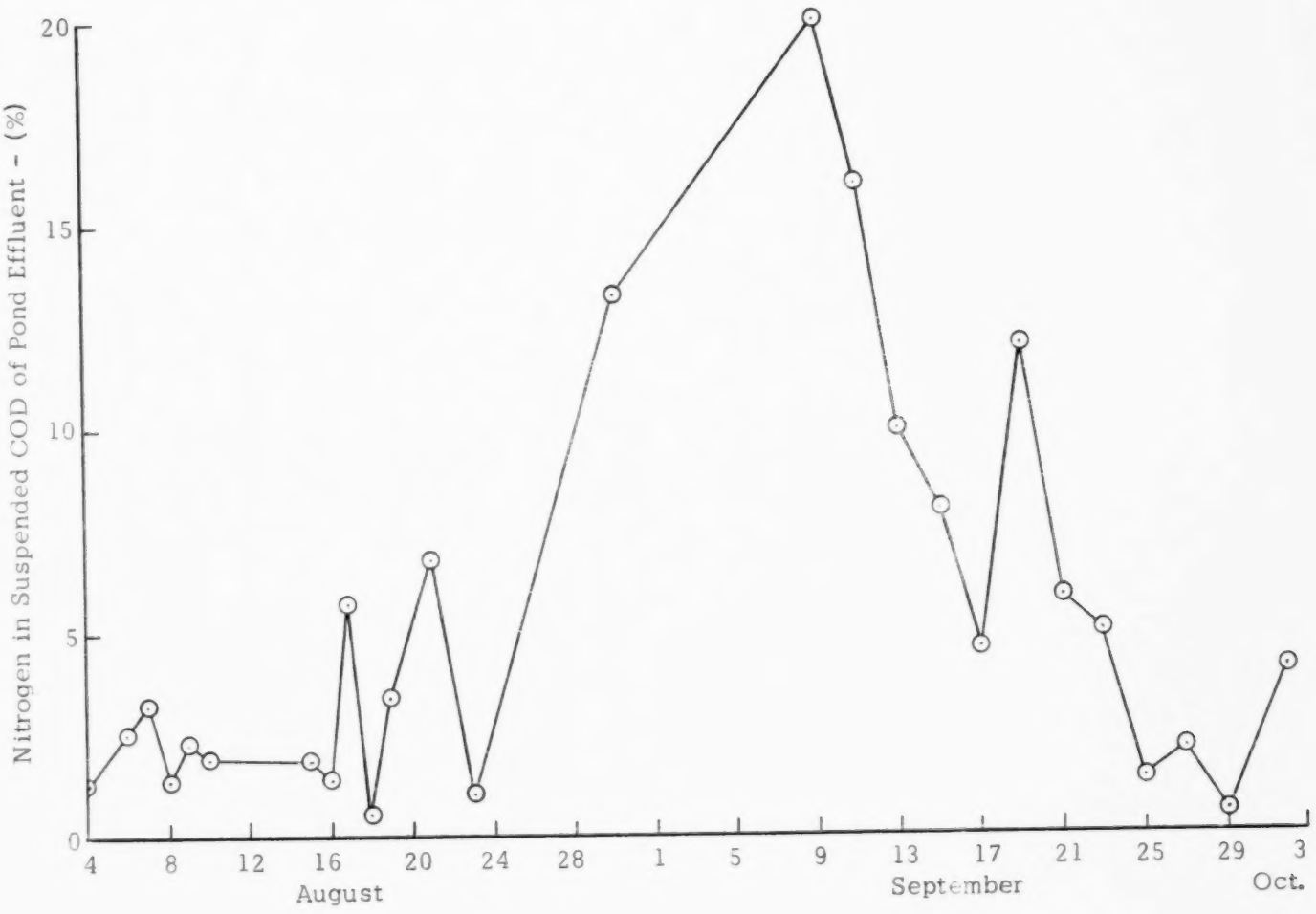


FIG. 20. NITROGEN IN SUSPENDED FRACTION OF POND EFFLUENT

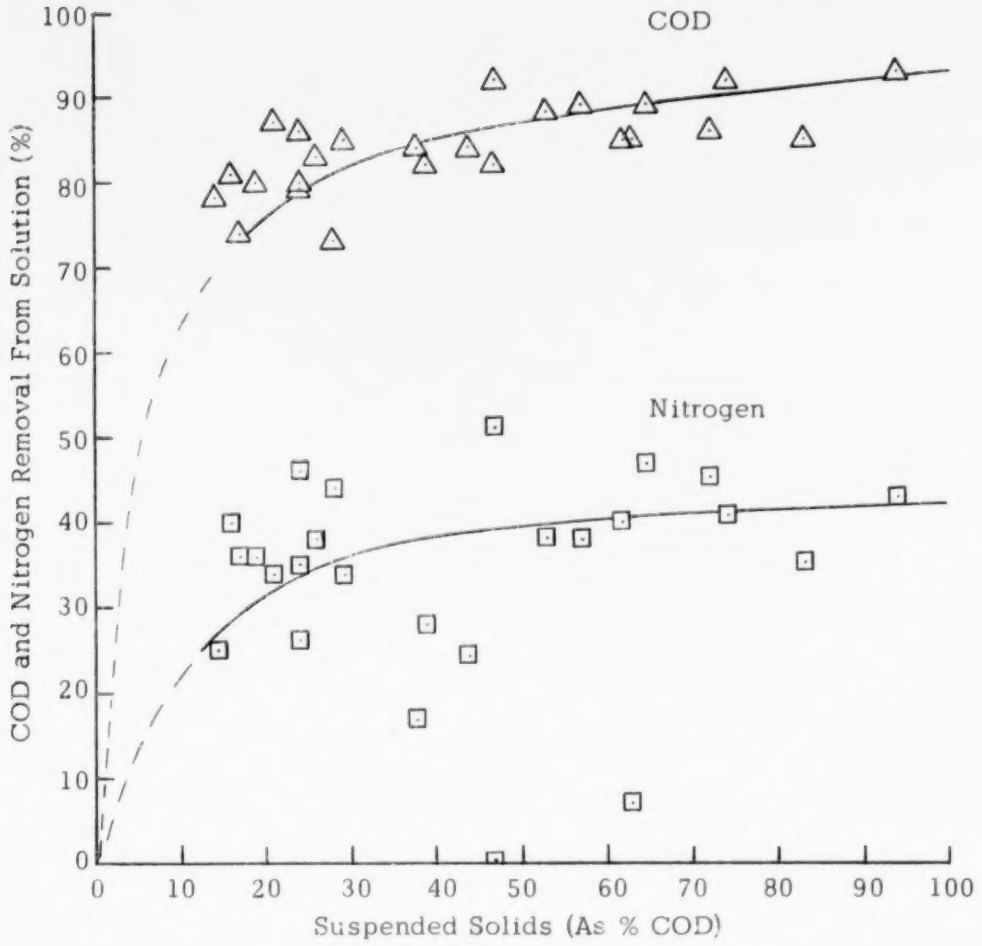


FIG. 21. REMOVAL OF COD AND NITROGEN FROM SOLUTION VS SUSPENDED SOLIDS

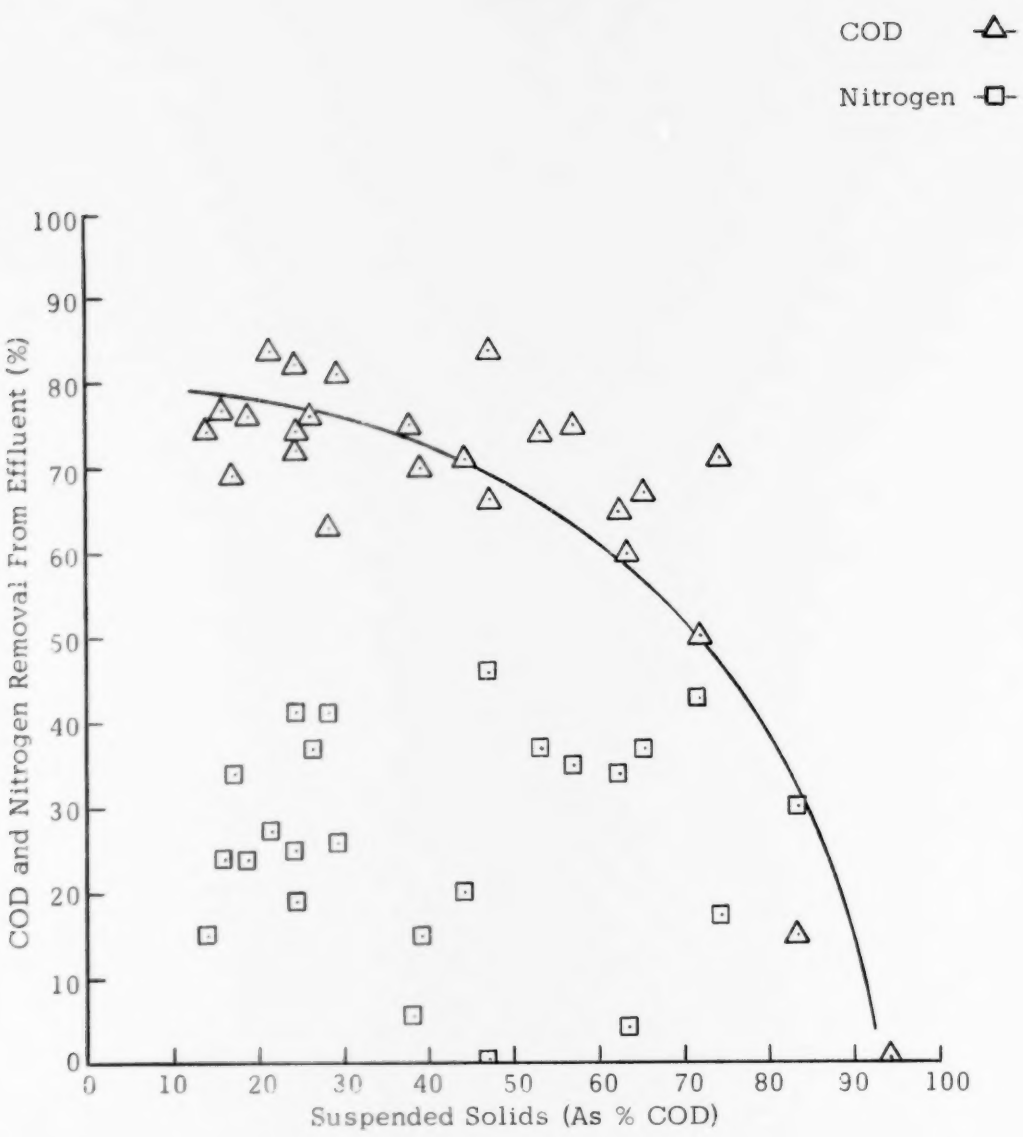


FIG. 22. REMOVAL OF COD AND NITROGEN FROM EFFLUENT VS SUSPENDED SOLIDS

the total loss of COD and total-nitrogen in the effluent, as compared to influent value, is plotted with respect to COD solids. Since the suspended solids are included in this case, the curve shows a definite decrease in removal of COD with increased solids.

The relationship between nitrogen removal and the amount of solids present is not as clear as in the case of COD. However, the amount of nitrogen removed from solution follows a similar pattern to that of COD (Fig. 21). Where COD removal was greater than 90% in some cases, nitrogen removal did not go much beyond 45%, and the one time it reached 52% the amount of solids was not very high. In the case of Fig. 22 (total loss = loss from solution + loss from suspension), nitrogen removal was widely scattered with respect to solids and removal values did not go beyond 46%.

APPENDIX A

TABLE 3. PROFILE CHARACTERISTICS

DATE: July 12, 1966

Depth	DO, mg/l		Temp. °C		pH		ORP	
cm	8 a.m.	8 p.m.	8 a.m.	8 p.m.	8 a.m.	8 p.m.	8 a.m.	8 p.m.
0	0.0	5.7	26.5	32.5	7.50	8.05	+74	+125
10		4.9	27.3	32.4	7.40	7.75	+56	+140
20		2.0	27.5	30.0	7.32	7.70	+38	+149
30		0.4	27.5	28.8	7.35	7.55	+38	+149
40		0.35	27.5	28.2	7.32	7.45	+26	+ 68
50		0.0	27.5	28.0	7.40	7.40	+20	+ 38
60			27.5	27.8	7.30	7.35	+ 8	+ 26
70			27.5	27.8	7.40	7.35	+ 8	+ 26
90			27.5	27.4	7.28	7.30	- 4	+ 20
110			27.5	27.4	7.25	7.30	-16	+ 14
150			27.3	27.0	-	-	-	-
150			27.3	27.0	-	-	-	-
170			27.0	26.8	-	-	-	-

DATE: October 15, 1966

Depth	DO, mg/l		Temp. °C		pH		ORP	
cm	8 a.m.	8 p.m.	8 a.m.	8 p.m.	8 a.m.	8 p.m.	8 a.m.	8 p.m.
0	0.0	4.0	24.3	25.1	7.70	8.05	+86	+170
10		4.0	24.3	25.1	7.65	8.10	71	146
20		4.0	24.3	25.1	7.65	8.10	62	134
30		4.0	24.3	25.0	7.65	8.05	83	128
40		3.2	24.2	25.0	7.65	8.00	74	98
50		1.0	24.2	24.2	7.60	7.80	86	77
60		0.0	24.2	23.9	7.65	7.55	86	47
80			24.1	23.7	7.55	7.55	80	35
100			24.0	23.6	7.55	7.55	68	35
120			24.0	23.3	7.40	7.50	56	32
140			23.9	23.2	-	-	-	-
160			23.9	23.2	-	-	-	-

TABLE 4. BIOCHEMICAL OXYGEN DEMAND OF STARLAC

Starlac Concentration = 1000 mg/l

Time Days	BOD Run 1	Run 2	Run 3	Average mg/l
1	140	165	0	100
2	450	165	330	315
3	580	525	540	550
4	675	562	555	595
5	665	667	615	650
6	-	690	570	630
7	685	645	750	695
9	685	818	795	760
11		772	720	745
13		690	645	670
15		877	735	800
17		698	675	690
19		810	780	795
22		690	690	690

TABLE 5. COD, TOTAL NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: August 4

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	29.0	3.90	3.90	<0.1	55.0	4.25
16	24.2	4.70	3.15	<0.1	57.0	5.20
30	14.5	4.70	4.00	<0.1	38.0	5.10
42	14.5	4.75	3.50	<0.1	38.0	5.20
54	24.2	5.05	3.60	<0.1	28.5	5.10
66	-	-	-	-	-	-

DATE: August 6

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	9.7	4.05	3.30	<0.1	203.0	8.90
16	38.6	4.85	4.40	<0.1	53.2	4.90
30	38.6	4.10	3.60	<0.1	48.4	5.00
42	29.0	4.50	2.90	<0.1	58.0	4.95
54	19.3	4.70	3.50	<0.1	48.4	5.10
66	-	-	-	-	-	-

DATE: August 7

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	19.9	3.90	2.80	<0.1	115.0	4.20
16	20.6	4.30	2.80	<0.1	28.8	4.50
30	20.2	4.40	3.05	<0.1	28.8	4.60
42	18.6	4.40	3.40	<0.1	19.2	4.50
54	21.0	4.30	3.05	<0.1	38.4	4.60
66	-	-	-	-	-	-

TABLE 5. - (cont.) COD, TOTAL-NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: August 8

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	36.2	3.90	3.60	<0.10	50.0	4.10
16	28.6	5.20	3.05	<0.10	70.0	5.30
30	32.6	4.80	3.60	<0.10	42.4	5.10
42	34.5	4.20	3.75	<0.10	58.0	5.10
54	30.9	4.40	2.80	<0.10	38.5	5.00
66	-	-	-	-	-	-

DATE: August 9

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$N	Unfiltered COD	T-N
0	16.5	3.70	1.75	<0.10	46.4	4.40
16	24.6	4.70	2.05	<0.10	43.2	5.20
30	18.0	4.40	2.70	<0.10	28.6	4.50
42	19.9	4.30	2.60	<0.10	23.5	4.70
54	23.7	4.80	2.30	<0.10	41.8	5.20
66	-	-	-	-	-	-

DATE: August 10

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	20.5	3.60	1.65	<0.10	72.5	3.70
16	30.9	4.50	2.05	<0.10	42.6	5.20
30	22.0	4.00	3.05	<0.10	25.4	4.50
42	23.0	3.90	2.60	<0.10	26.8	4.55
54	26.4	4.30	2.70	<0.10	33.8	5.00
66	-	-	-	-	-	-

TABLE 5. - (cont.) COD, TOTAL-NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: August 15

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	16.5	3.70	2.70	<0.10	39.2	4.10
16	27.8	4.80	3.55	<0.10	61.0	5.60
30	21.5	4.40	3.35	<0.10	50.5	5.00
42	17.0	4.10	3.30	<0.10	39.4	4.70
54	22.2	-	3.40	<0.10	38.0	4.70
66	-	-	-	-	-	-

DATE: August 16

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	34.8	3.90	2.50	<0.10	42.4	3.90
16	19.8	3.95	3.00	<0.10	58.0	4.70
30	22.0	4.00	3.10	<0.10	31.3	4.40
42	22.9	4.10	3.10	<0.10	27.8	4.40
54	27.2	-	3.20	<0.10	30.2	4.50
66	-	-	-	-	-	-

DATE: August 17

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	10.6	3.95	2.70	<0.10	38.3	5.00
16	16.2	4.10	3.30	<0.10	49.3	5.20
30	14.9	4.50	3.30	<0.10	43.0	4.90
42	13.4	4.60	3.35	<0.10	40.0	4.80
54	17.1	4.10	3.35	<0.10	41.0	4.90
66	-	-	-	-	-	-

TABLE 5. - (cont.) COD, TOTAL-NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: August 18

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	14.7	3.90	2.85	<0.10	31.5	4.00
16	17.8	4.20	3.10	<0.10	57.5	4.90
30	24.0	4.30	3.15	<0.10	49.4	4.70
42	14.5	4.10	3.15	<0.10	46.0	4.70
54	16.0	4.10	3.15	<0.10	55.0	4.70
66	-	-	-	-	-	-

DATE: August 19

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	28.5	3.70	2.80	<0.10	38.2	4.00
16	30.7	4.20	3.40	<0.10	36.4	4.50
30	20.8	4.30	3.40	<0.10	42.5	4.30
42	25.3	4.40	3.35	<0.10	37.0	4.40
54	24.0	4.40	3.40	<0.10	42.2	4.50
66	-	-	-	-	-	-

DATE: August 21

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	14.8	3.50	2.80	<0.10	21.5	3.90
16	14.6	3.90	3.10	<0.10	36.1	4.50
30	19.2	4.10	3.10	<0.10	43.6	4.60
42	23.6	4.00	3.05	<0.10	49.0	4.70
54	22.5	4.00	3.00	<0.10	52.0	4.60
66	-	-	-	-	-	-

TABLE 5. - (cont.) COD, TOTAL-NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: August 23

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	18.0	3.70	2.90	<0.10	35.4	3.90
16	14.6	3.90	3.15	<0.10	45.2	4.40
30	19.6	3.90	3.25	<0.10	33.2	5.00
42	21.7	4.10	3.25	<0.10	35.9	4.60
54	20.2	4.50	3.25	<0.10	33.8	5.00
66	16.7	4.30	3.30	<0.10	35.5	4.80

DATE: August 30

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	15.7	3.90	3.35	<0.10	19.0	4.30
16	14.6	3.90	3.40	<0.10	20.9	4.00
30	17.9	4.30	3.45	<0.10	25.5	4.70
42	16.5	4.10	3.50	<0.10	28.4	4.70
54	17.8	4.50	3.45	<0.10	23.4	4.50
66	18.8	4.50	3.60	<0.10	29.0	4.80

DATE: September 1

Date Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	16.3	-	3.20	<0.10	26.3	-
16	15.5	-	3.30	<0.10	29.9	-
30	20.2	-	3.50	<0.10	34.5	-
42	16.1	-	3.50	<0.10	28.3	-
54	16.1	-	3.70	<0.10	31.9	-
66	16.1	-	3.75	<0.10	29.9	-

TABLE 5. - (cont.) COD, TOTAL-NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: September 9

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	27.0	4.00	4.00	<0.10	32.1	5.05
16	16.6	4.00	4.00	<0.10	26.6	5.00
30	20.6	4.30	4.20	<0.10	27.6	5.05
42	22.6	4.10	4.10	<0.10	25.9	5.10
54	23.7	4.10	4.00	<0.10	33.2	5.20
66	25.9	4.20	4.10	<0.10	40.0	5.50

DATE: September 11

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	21.9	4.20	4.20	<0.10	27.0	5.00
16	17.5	4.10	4.10	<0.10	27.5	5.00
30	20.8	4.20	4.20	<0.10	30.5	5.15
42	20.8	4.05	4.00	<0.10	29.9	5.10
54	25.2	4.00	4.00	<0.10	36.1	5.15
66	15.45	4.40	4.30	<0.10	42.2	5.80

DATE: September 13

Depth Inches	Filtered COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	Unfiltered COD	T-N
0	19.0	4.50	4.20	<0.10	24.6	5.10
16	16.8	4.60	4.20	<0.10	25.4	4.90
30	22.6	4.65	4.30	<0.10	32.5	5.15
42	17.9	4.45	4.20	<0.10	24.3	5.05
54	19.2	4.45	4.30	<0.10	32.9	5.10
66	21.3	4.60	4.30	<0.10	33.0	5.40

TABLE 5. - (cont.) COD, TOTAL-NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: September 15

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	10.4	4.40	4.40	<0.10	18.8	5.10
16	6.3	4.60	4.40	<0.10	23.6	5.10
30	6.6	4.40	4.20	<0.10	32.1	5.25
42	6.4	4.45	4.20	<0.10	29.9	5.20
54	10.6	4.40	4.20	<0.10	31.2	5.25
66	19.3	4.50	4.20	<0.10	27.8	5.30

DATE: September 17

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	18.0	4.45	4.30	<0.10	29.3	5.00
16	17.0	4.60	4.30	<0.10	22.9	5.00
30	14.4	4.40	4.30	<0.10	23.4	5.00
42	20.3	4.70	4.40	<0.10	25.5	5.10
54	19.4	4.40	4.40	<0.10	26.0	5.05
66	16.6	5.05	4.80	<0.10	22.9	5.40

DATE: September 19

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	31.5	4.40	4.00	<0.10	35.5	5.00
16	24.5	4.30	4.10	<0.10	30.7	4.80
30	24.8	4.60	4.20	<0.10	43.0	5.25
42	18.4	4.40	4.10	<0.10	30.7	5.05
54	30.3	4.20	3.60	<0.10	44.9	5.20
66	28.8	5.20	3.90	<0.10	42.0	5.50

TABLE 5. - (cont.) COD, TOTAL-NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: September 21

Depth Inches	Filtered COD	Filtered T-N	Filtered NH_3-N	Filtered $NO_3^-+NO_2^-$-N	Unfiltered COD	Unfiltered T-N
0	21.7	4.30	3.90	<0.10	36.6	5.10
16	16.3	4.20	3.90	<0.10	39.4	5.05
30	21.3	4.40	3.90	<0.10	42.4	5.20
42	15.9	4.30	4.00	<0.10	44.7	5.60
54	30.9	4.10	3.50	<0.10	46.4	5.10
66	36.1	-	4.30	<0.10	56.4	-

DATE: September 23

Depth Inches	Filtered COD	Filtered T-N	Filtered NH_3-N	Filtered $NO_3^-+NO_2^-$-N	Unfiltered COD	Unfiltered T-N
0	24.6	4.30	4.30	<0.10	32.8	4.70
16	21.9	4.30	4.20	<0.10	30.1	4.40
30	34.1	4.10	4.00	<0.10	45.7	5.70
42	30.7	3.80	3.70	<0.10	39.4	4.40
54	30.0	4.20	4.20	<0.10	37.1	4.30
66	18.4	4.10	3.90	<0.10	51.0	4.30

DATE: September 25

Depth Inches	Filtered COD	Filtered T-N	Filtered NH_3-N	Filtered $NO_3^-+NO_2^-$-N	Unfiltered COD	Unfiltered T-N
0	19.5	4.20	4.10	<0.10	36.0	4.40
16	19.9	4.10	3.80	<0.10	33.0	4.50
30	19.1	3.90	3.80	<0.10	37.6	4.40
42	23.1	4.10	3.80	<0.10	37.3	4.70
54	21.9	3.90	3.80	<0.10	37.3	4.70
66	16.8	4.60	4.00	<0.10	25.2	4.80

TABLE 5. - (cont.) COD, TOTAL-NITROGEN, AMMONIA-NITROGEN AND NITRATE & NITRITE-NITROGEN

DATE: September 27

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	16.5	4.00	4.00	<0.10	23.1	4.10
16	17.3	3.90	3.90	<0.10	20.7	4.30
30	25.5	4.40	4.40	<0.10	45.0	4.60
42	20.7	3.90	3.90	<0.10	20.7	4.30
54	23.1	4.00	4.00	<0.10	55.0	4.30
66	25.2	4.00	4.00	<0.10	29.4	4.60

DATE: September 29

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	14.8	4.20	4.20	<0.10	40.2	4.3
16	15.5	4.20	4.20	<0.10	29.8	5.9
30	24.3	4.40	4.20	<0.10	38.2	4.7
42	17.7	4.80	4.20	<0.10	51.8	5.0
54	21.0	4.20	3.70	<0.10	47.7	4.8
66	12.6	4.60	4.20	<0.10	50.5	4.8

DATE: October 2

Depth Inches	Filtered				Unfiltered	
	COD	T-N	NH_3-N	$NO_3^-+NO_2^-$-N	COD	T-N
0	17.3	4.00	3.90	<0.10	27.3	4.40
16	17.3	3.80	3.80	<0.10	39.0	4.40
30	13.0	4.00	3.90	<0.10	26.0	4.40
42	16.8	4.00	3.90	<0.10	26.0	4.60
54	12.6	4.00	5.80	<0.10	30.3	4.40
66	37.8	4.40	4.30	<0.10	42.0	4.90

APPENDIX B

MATERIAL BALANCE

A) Chemical Oxygen Demand:

1. Acclimation Period (No Feeding)

a) March 21, 1966

Pond completely mixed, COD = 150 mg/l
Volume of pond = 408 l

Initial COD of pond contents (150 mg/l x 408) = 61,250 mg

b) March 21 to June 23

Pond remained idle, COD dropped to 65 mg/l
(No influent during this period)

2. Adjustment Period

June 23 to August 4

Continuous Feeding, Rate = 2100 mg/day

Influent COD (43 days x 2100 mg/day) = 90,400 mg

3. Test Period

August 4 to October 7

Continuous Feeding, Rate = 2100 mg/day

Influent COD (64 days x 2100 mg/day) = 134,000 mg

TOTAL COD 285,650 mg

4. Effluent

Rate = 800 mg/day (108 days x 800 mg/day) = 86,400 mg

TOTAL COD REMOVED 199,250 mg

5. Bottom Sediment (6.4 l x 11,670 mg/l) = 74,500 mg

LOST AS CO_2 124,750 mg

B) Total Nitrogen:

1. Acclimation Period (No Feeding)

March 21, 1966 Total nitrogen = 8.6 mg/l

Volume = 408 l

Initial total nitrogen of pond contents = 3,520 mg

2. Adjustment Period

June 23 to August 4

Continuous Feeding, Rate = 122 mg/day

Influent total nitrogen (43 days x 122 mg/day) = 5,250 mg

3. Test Period

August 4 to October 7

Continuous Feeding, Rate = 122 mg/day

Influent total nitrogen (64 days x 122 mg/day) = 7,800 mg

TOTAL NITROGEN 16,570 mg

4. Effluent

Rate = 86 mg/day (108 days x 86 mg/day) = 9,300 mg

TOTAL NITROGEN REMOVED 7,270 mg

5. Bottom Sediment (6.4 l x 361 mg.l) = 2,310 mg

NITROGEN LOST AS GAS 4,960 mg

BIBLIOGRAPHY

1. Assenzo, J. R., Reid, G. W., "The Removal of Nitrogen and Phosphorus by Bio-Oxidation Ponds in Central Oklahoma," Natn. Symp. on San. Engr. Res., Dev. and Design, The Pennsylvania State University, Univ. Park, Penn., July, 1965.

2. Bartsch, A. F., "Induced Eutrophication - A Growing Water Resource Problem," Algae and Metropolitan Wastes, R. A. Taft SEC, TR W61-3, 1961.

3. Beck, W. M., "The Biological Removal of Nitrogenous Compounds from Sewage Treatment Plant Effluents," Biological Problems in Water Pollution, Third Seminar, Aug. 1962, U.S. Dept. HEW, PHS.

4. Chu, S. P., "The Influence of the Mineral Composition of the Medium on the Growth of Planktonic Algae," Jour. Ecol., 31, 1943.

5. Clifton, C. E., Introduction to Bacterial Physiology. McGraw-Hill Book Company, Inc., New York: 1957.

6. Conn, E. E., and Stumpf, P. K., Outlines of Biochemistry. John Wiley and Sons, Inc., New York: 1963.

7. Davis, Ernst, Personal Communication, March 1966.

8. Eckenfelder, W. W., "Theory and Design of Biological Oxidation Systems for Organic Waste," A Lecture Presented at the International Course in Sanitary Engineering at the University of Delft, Holland, June 1965.

9. Eckenfelder, W. W. and Gloyna, E. F., "New Aspects of Biological Waste Treatment Design," Paper Given at the 35th International Congress of Industrial Chemistry, September 1964, Warsaw, Poland.

10. Fitzgerald, G. P., "Stripping Effluents of Nutrients by Biological Means," Algae and Metropolitan Wastes, R. A. Taft SEC, TR W61-3, 1961.

11. Fitzgerald, G. P. and Rohlich, G. A., "An Evaluation of Stabilization Pond Literature," Sewage and Industrial Wastes, 30, 10, 1213, 1958.

12. Fogg, G. E., The Metabolism of Algae. John Wiley and Sons. Inc., New York:1953.

13. Fry, B. A., The Nitrogen Metabolism of Micro-Organisms. John Wiley and Sons, Inc., New York:1955.

14. Gates, W. E. and Borchardt, J. A., "Nitrogen and Phosphorus Extraction from Domestic Waste Water Treatment Plant Effluents by Controlled Algal Cultures," Journ. WPCF, 36, 4, 443, 1964.

15. Gearheart, R. A., "Nitrogen Cycle in Biological Unit Operation," Paper presented at the Texas Section ASCE, Fort Worth, October 9, 1965.

16. Gerloff, G. C., and Skoog, F., "Nitrogen as a Limiting Factor for the Growth of Microcystis Aeroginosa in Southern Wisconsin Lakes," Ecology, 38, 1957.

17. Gloyna, E. F., "Waste Stabilization Pond Design," Manufacturing Chemists Association Lecture Notes, The University of Texas, 1967.

18. Hermann, E. R., "Stabilization Pond as a Nitrate Reducing Reactor," Journ. SED, ASCE, 88, SA5, 1962.

19. Hewitt, L. F., Oxidation-Reduction Potentials in Bacteriology and Biochemistry. E & S Livingstone Ltd., Edinburgh, Great Britain: 1950.

20. Hodgson, H. T., "Stabilization Ponds for a Small African Urban Area," Jour. WPCF, 36, 1, 61, 1964.

21. Horasawa, I., Myrata, K., Ezaki, T., Suzuki, K., "Nitrogen Removal from Sewage and Night Soil in Stabilization Ponds," Second International Conference on Water Pollution Research, Tokyo, Japan, 1964. Reprint.

22. Lewin, R. A., Physiology and Biochemistry of Algae. Academic Press, New York: 1962.

23. Loehr, R. C. and Stephenson, R. L., "An Oxidation Pond as a Tertiary Treatment Device," Jour. SED, ASCE, 91, SA3, June, 1965.

24. Mackenthun, K. M., "A Review of Algae, Lake Weeks, and Nutrients," Jour. WPCE, 34, 10, 1077, 1962.

25. Meron, A., Rebhun, M., and Sless, B., "Quality Changes as a Function of Detention Time in Waste Water Stabilization Ponds," Jour. WPCF, 37, 12, 1657, 1965.

26. Neel, J. K., and Hopkins, G. J., "Experimental Lagooning of Raw Sewage," Sewage and Industrial Wastes, 28, 11, 1326, 1956.

27. Neel, J. K., McDermott, J. H., and Monday Jr., C. A., "Experimental Lagooning of Raw Sewage at Fayette, Missouri," Jour. WPCF, 33, 6, 603, 1961.

28. Nichols, M. S., "Nitrates in the Environment," Jour. AWWA, 57, 10, 1319, 1965.

29. Oswald, W. J., Gohieke, C. G., Cooper, R. C., Geer, H. K., and Bronson, J. C., "Water Reclamation, Algal Products and Methane Fermentation," Jour. International Air & Water Pollution, 7, 6 & 7, August 1963.

30. Parker, C. D., "Microbiological Aspects of Lagoon Treatment," Jour. WPCF, 34, 2, 149, 1962.

31. Reid, G. W., and Assenzo, J. R., "The Removal of Nitrogen and Phosphorus by Slimes and Algae," Dept. of Sanitary Science and Public Health, University of Oklahoma, Norman, Oklahoma.

32. Ruttner, F., Fundamentals of Limnology. University of Toronto Press, Toronto: 1963.

33. Sawyer, C. N., "Basic Concepts of Eutrophication," Jour. WPCF, 38, 737, 1966.

34. Standard Methods for the Examination of Water and Wastewater. 12th Ed. American Public Health Association, Inc., New York: 1965.

35. Stanier, R. Y., Doudoroff, M., and Adelberg, E. A., The Microbial World. Prentice-Hall, Inc., Englewood Cliffs, New Jersey: 1964.

36. Task Group Report, "Nutrient-Associated Problems in Water Quality and Treatment," Jour. AWWA, 58, 10, 1337, 1966.

37. Thimann, K. V., The Life of Bacteria. 2nd Ed. The Macmillan Company, New York: 1963.

38. Wuhrmann, K., Lectures at The University of Texas, March 1966.